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CHANNEL CAPACITY ANALYSIS FOR BONEYARD CREEK IN URBANA ILLINOIS

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ABSTRACT

CHANNEL CAPACITY ANALYSIS FOR BONEYARD CREEK IN URBANA ILLINOIS

Flooding of the Boneyard Creek in the cities of Champaign and Urbana, Illinois has been a recurring problem since gradual urbanization of the area more than a century ago. Recently a new method has been developed to assess flooding problems along a channel system by hydraulically determining the capacities of the system and comparing them with the amount of water to be drained, which is determined hydrologically. In this report the determination of the capacities of the Urbana city portion of the Boneyard Creek for the 1997 channel conditions is presented. This capacity determination is achieved through the use of Yen and Gonzalez's method of hydraulic performance graph (HPG). Furthermore, the locations of the bottlenecks that are most critical to flooding are identified and the improved capacities with these bottlenecks removed are investigated. Results revealed that the overall capacity of the Urbana portion of the Boneyard for stages between 700.0 ft and 701.5 ft at its confluence with the Saline Branch is controlled by the limited capacity of the segment of the creek between the upstream side of the Main Street Bridge and the downstream side of the Lincoln Avenue Bridge. Other major bottlenecks are the Huey Bridge and the closed–top structures at the Phillips Recreation Center. Removal of Huey's Bridge will increase the system's capacity by approximately 40 cfs. Removal of both the Huey and Phllips Recreation Center bottlenecks will increase the system's overall capacity by about 100 cfs or 6%.

KEYWORDS – *Backwater curve/Boneyard Creek/*Bottleneck identification/*Channel capacity/Channel flow/Critical location/Drainage/Flood flow/Flood frequency/Hydraulic capacity/Hydraulic performance graph/Open channels/Overall hydraulic capacity/Runoff/Storm drainage/*Urban drainage

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1. INTRODUCTION

Since urbanization of the cities of Urbana and Champaign, Illinois started more than a century ago, flooding of the Boneyard Creek has been a recurring event. In Urbana, with the channel improvements of realignment, sheet-piling and deepening, the Boneyard flooding situation has been greatly improved. However, the pending channel improvement of the Boneyard Creek in Champaign and along the north campus of the University of Illinois at Urbana-Champaign has raised concern over the capacity of the portion of the Creek in the city of Urbana.

Recently two studies regarding the assessment of the channel carrying capacity as well as an analysis of bottlenecks and improvement alternatives for the Boneyard Creek along the campus have been conducted by Yen and González (1994, 1995). The carrying capacity of a channel is the discharge for which spilling overbank is about to occur anywhere within the channel for a specified downstream tailwater level.

A method for determining the hydraulic capacity of a channel system is based on the hydraulic performance graph (***HPG***) and rating curve of a channel reach was recently introduced by Yen and González (1994). The ***HPG*** of a channel reach is a set of curves showing the relationship between the upstream and downstream water stages for different discharges in the channel reach, essentially summarizing the characteristics of the flow profiles obtained from backwater computations. The method is applied in this study to determine the carrying capacity of the Urbana portion of the Boneyard Creek downstream of the Lincoln Avenue Bridge. The capacity for this portion of the Boneyard for its conditions of May 1997 has been determined as a function of the water stage at its confluence with Saline Branch.

To better identify the bottlenecks and stations along the channel subject to threshold capacity conditions, the capacity of the Boneyard is studied by further dividing the creek into two segments: **(a)** the downstream segment, located between the confluence of the Boneyard with Saline Branch (Station 0+085) and the upstream end of the Main Street Bridge (Station 4+755); and **(b)** the upstream segment, which goes from the upstream end of the Main Street Bridge (Station 4+755) to the downstream end of the Lincoln Avenue Bridge (Station 6+955). The overall capacity is determined for each of these segments and for both segments as a whole. Furthermore, the effect of the first and second bottlenecks on the overall capacity of the creek between the confluence and Lincoln Avenue as a whole is also determined.

2. DESCRIPTION OF BONEYARD CREEK IN URBANA

The Boneyard Creek drains a total area of 6.15 square miles of the Cities of Champaign and Urbana, which includes a large portion of the University of Illinois campus. Almost the total area of the watershed drained by the Boneyard is urbanized. A cumulative area of 4.09 square miles is drained by the creek when it reaches the downstream side of the Lincoln Avenue Bridge. Of this area, 3.21 square miles correspond to the City of Champaign up to the downstream side of the Wright Street Bridge, whereas the remaining 0.88 square miles correspond to the drained area of the campus portion of the University of Illinois. The Boneyard flows through the Campus of the University of Illinois in the east direction and turns northeast near Cedar Street in Urbana to its confluence with Saline Branch (Fig. 2.1). The length of stretch of the Boneyard flowing through the City of Urbana between the downstream side of the Lincoln Avenue Bridge (Station 0+085) and the confluence with Saline Branch (Station 6+955) is 6,870 ft (1.3 mi), see Fig. 2.2.

The segment of the creek between the upstream side of the Race Street Bridge (Station 3+600) and the dowsntream side of the Lincoln Avenue Bridge (Station 6+955) was channelized between 1963 and 1964. These channel improvements consisted of steel sheet piling on the side-walls and reinforced concrete on the bottom. Downstream of this channelized portion the side-walls of the creek consist mainly of earthen sides with or without vegetation and earthen sides protected with gavions, depending on the location. Information on individual cross sections is given in Appendix A. The longitudinal profile of the channel bed (trajectory of the lowest point in a cross section) of this stretch of the Boneyard together with the profiles of the banks is shown in Fig. 2.3.

Along the Urbana portion of the Boneyard Creek there are thirteen bridges (three of them consisting of twin box culverts), one culvert, and one reach covered with precast concrete sheets. The stretch of the creek flowing by the Phillips Recreation Center (between downstream side of the Mc Cullough Street Bridge and upstream side of the Springfield Avenue Bridge, from Station 5+205 to Station 5+795), is conformed by a group of four closing-type reaches. These reaches are: (a) the Mc Cullough Street Bridge; (b) a 200-foot long concrete tunnel build in 1926 to accommodate Thornburn School which previously occupied this site; (c) a 240-foot long segment of the channel with steel sheet pile sides, concrete floor and precast concrete deck ceiling constructed in 1963; and (d) the Springfield Avenue Bridge. These reaches are designated in Fig. 2.3 as reaches 19a, 19b, 19c, and 19d, respectively.

From the Greeley and Hansen report of 1980 on the storm sewer system of the City of Urbana, 20 major sewers draining into the Boneyard Creek between stations 0+085 and 6+675 were identified and verified through field inspection. The location, manhole number, rim and invert elevations, and pertinent remarks for each of these sewers' outlets are summarized in Table 2.1.

Table 2.1 Major Sewers Draining into Boneyard Creek between its Confluence with Saline Branch and Lincoln Avenue.

Manhole Number	Manhole Location and Pipe Description	Elevations [ft] Rim	Invert	Remarks
59115A	Boneyard Ditch (E of Park & Sycamore)		701.34	12" sewer outlet
59114A	Boneyard Ditch (E of Park & Sycamore)		693.87	12" sewer outlet
58148E	University & Boneyard Ditch		695.46	24" sewer outlet
69134B	University & Boneyard Ditch		690.13	84" sewer outlet
58127B	36" CC to NE (58127B)	703.58	693.64	
58118B	Broadway & Boneyard Ditch		699.10	12" sewer outlet (15")
58119A	Broadway & Boneyard Ditch		699.89	12" sewer outlet (15")
58133A	Broadway & Boneyard Ditch		696.34	
58125A	Boneyard Ditch (Race & Broadway)		696.99	
57226A	Race & Boneyard Ditch		703.46	18" sewer outlet
	D/S of Main St. Culvert (from south bank)			6' sewer outlet
68113A	Main & Central	708.45		
	15" CL to SE (Boneyard Ditch)		703.00	
68136A	Springfield & Mc Cullough	712.58		
	24" CC to N (Boneyard Ditch)		708.37	
	15" CL to N (Boneyard Ditch)		706.66	
68108	Stoughton (Coler & Mc Cullough)	708.40		
	30" CC to SE (Boneyard Ditch)		701.02	18" CMP 1/2 way to outlet
68105	Springfield & Coler	712.47		
	54" CC to E (Ooulet)		702.77	
68152	D/S of Coler Ave.			
68106	Coler (Springfield & Boneyard Ditch)	711.24		
	12" CC to S(Boneyard Ditch)		705.61	
68150	Elm (Busey & Coler)	710.02		
	12x7.5 ft BR to N (Boneyard Ditch) & S (68151)		704.43	Arch
68120A	Busey & Boneyard Ditch		705.06	10" sewer outlet (15" opening)
68149A	Busey & Boneyard Ditch	712.01	706.96	10" sewer outlet

Major storm sewers draining into this stretch of the Boneyard Creek are indicated as heavy solid lines in Fig. 2.3. The cumulative drainage areas at key locations along the Boneyard between Wright Street and the Confluence of Saline Branch are listed in Table 2.2. The location of bridges and other structures considered for dividing the Urbana portion of Boneyard Creek into study reaches together with the length, bed and bank elevations, low and upper chord delevations of bridges and closing-tope type structures, conditions of the channel surface, and Manning's roughness coefficient of the reaches are given in Table 2.3.

Table 2.2 Drainage Area at Selected Locations along Boneyard Creek.

Location	Station	Area Drained square miles
D/S of Wright Street Bridge	9+705	3.21
D/S of Burrill Avenue Bridge	9+335	3.25
USGS Gaging Station	9+128	3.28
D/S of Mathews Avenue Bridge	8+785	3.46
D/S of Goodwin Avenue Bridge	8+310	3.64
U/S of Lincoln Avenue Bridge	7+105	4.09
D/S of 12.5×7.5 ft Culvert	6+285	4.42
D/S of Coler Street Bridge	6+065	4.57
U/S of 200-foot reinforced concrete tunnel by Pillips Recreation Center	5+460	4.59
U/S of Main Street Bridge	4+755	4.63
D/S of Main Street Bridge	4+465	4.97
D/S of Race Street Bridge	3+600	4.98
U/S of Bradway Avenue Bridge	3+085	5.08
U/S of Vine Street Bridge	2+395	5.10
U/S of University Avenue Bridge	1+940	6.10
Confluence with Saline Branch	0+085	6.15

These values are estimated only at locations where sewers with important lateral flow contributions discharge into the creek.

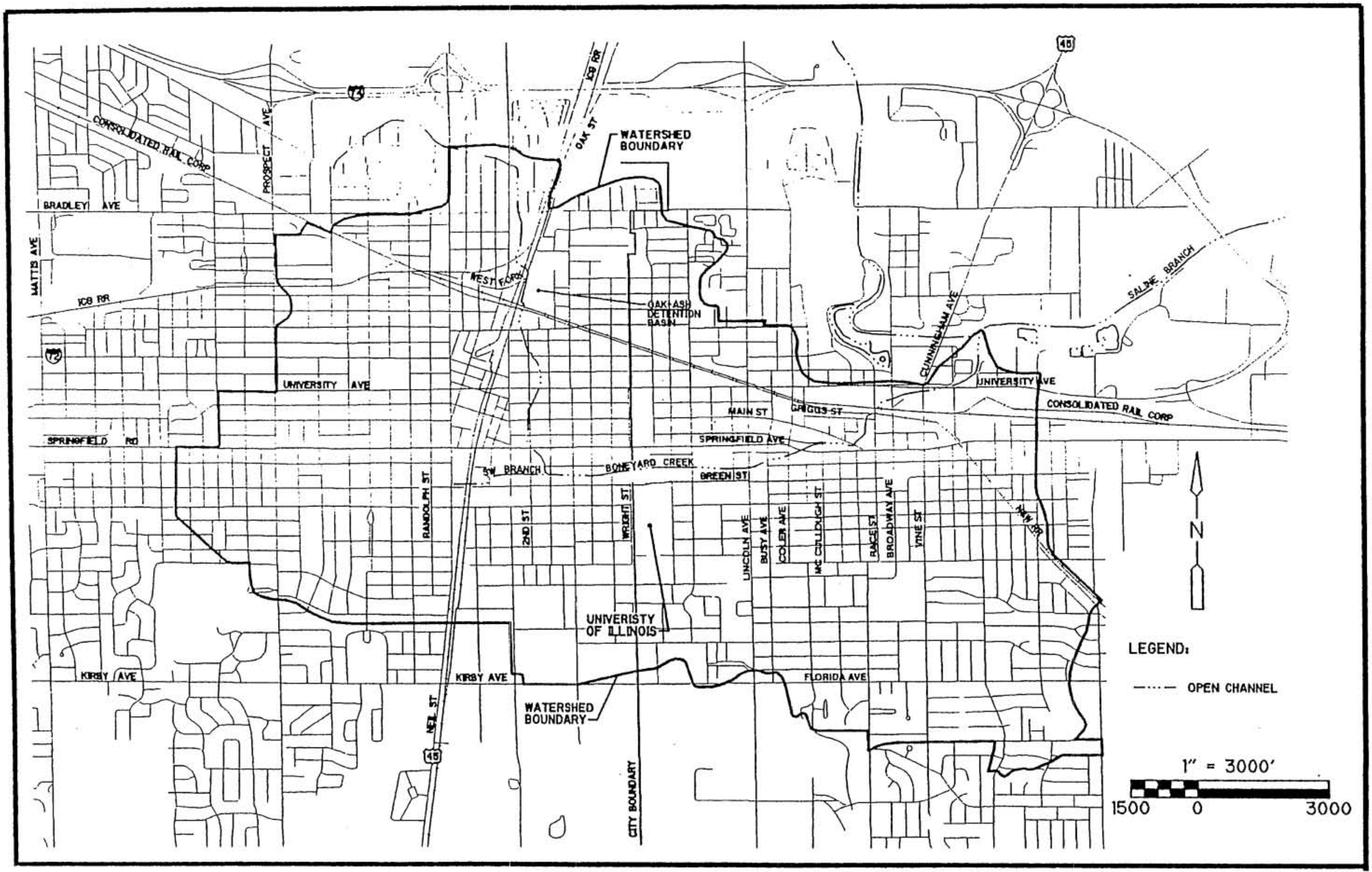

Fig. 2.1 Boneyard Creek Watershed.

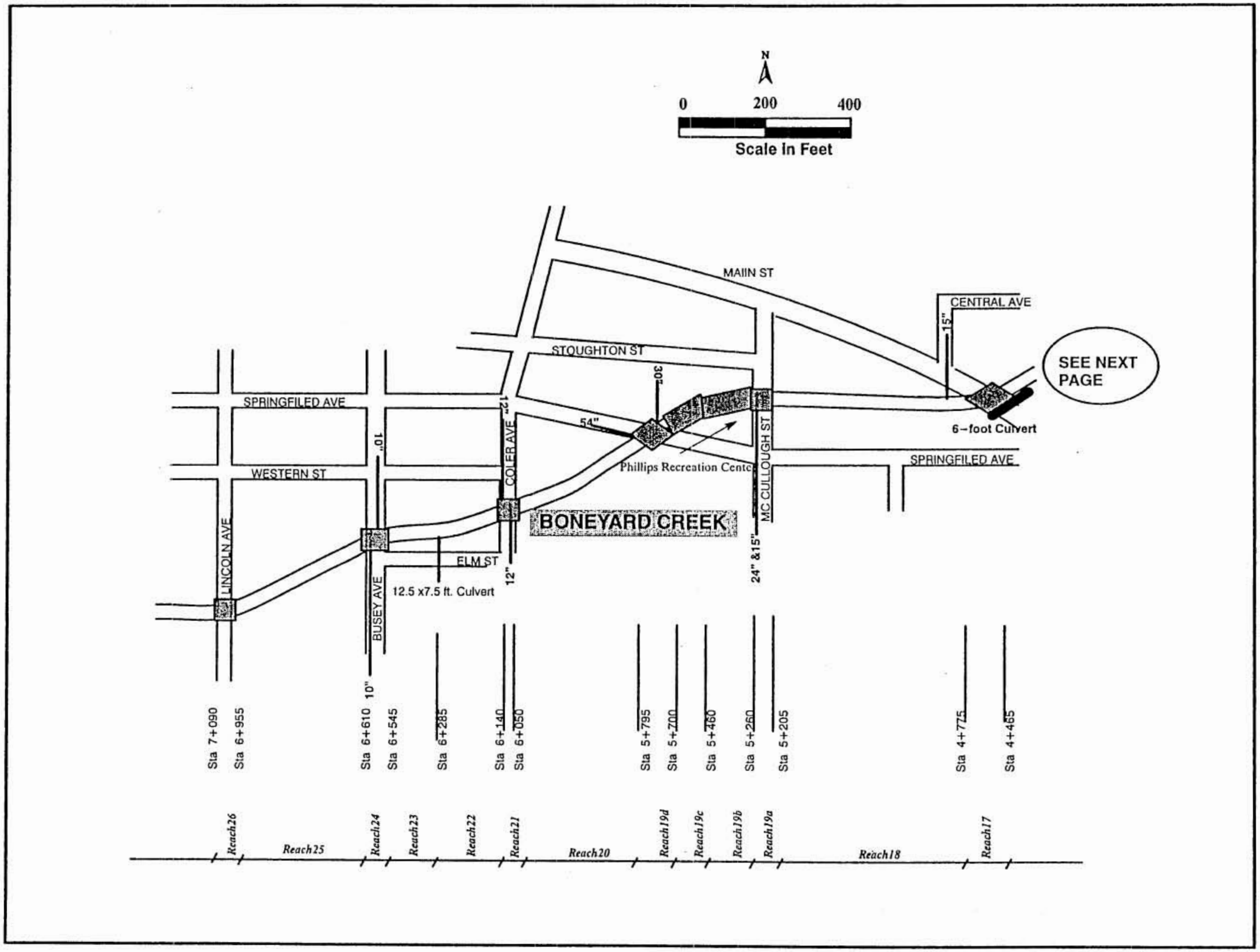

Fig. 2.2 Location Map of Boneyard Creek in Urbana between Lincoln Avenue and Confluence with Saline Branch, Condition of May 1997.

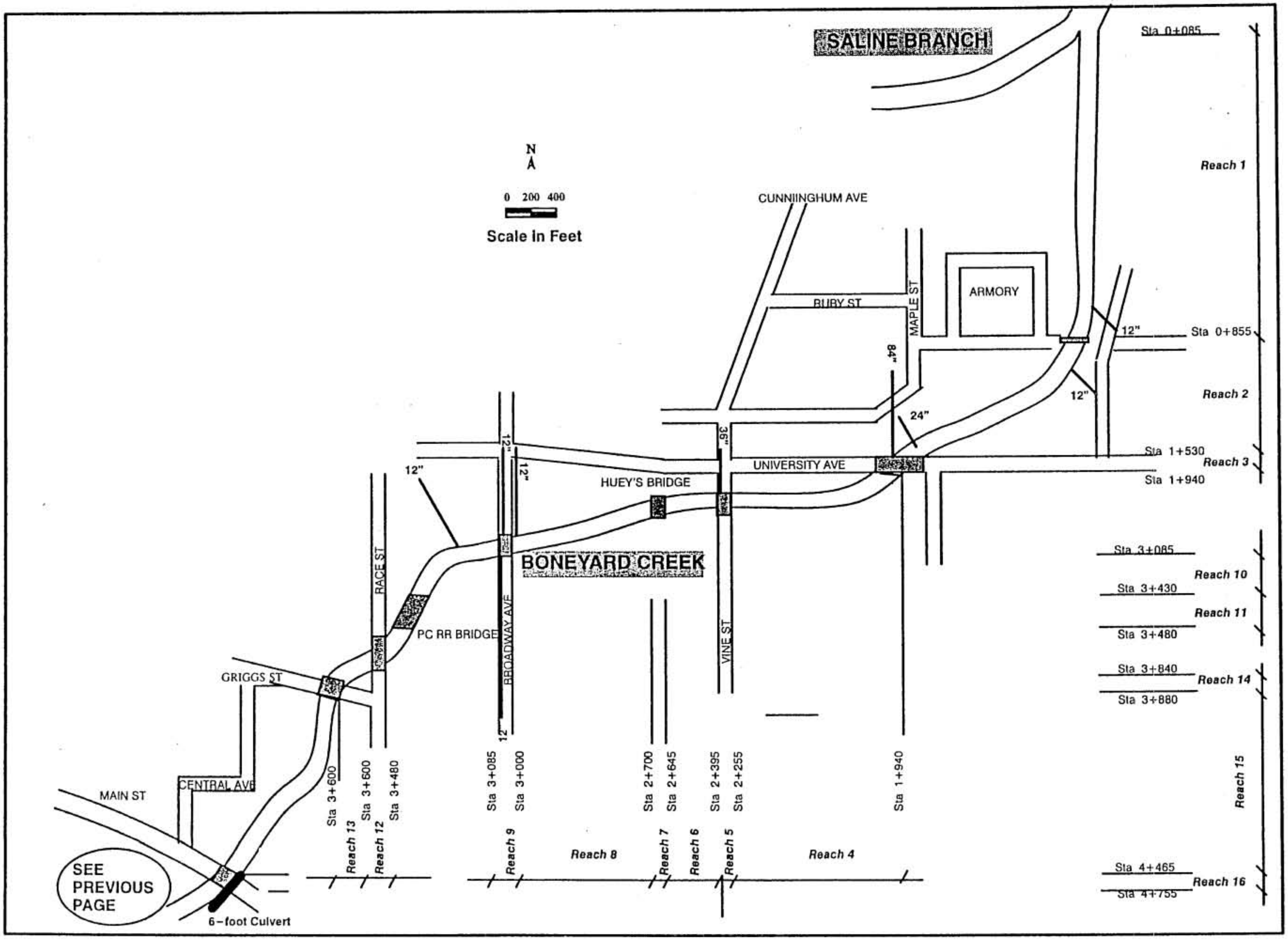

Fig. 2.2 Location Map of Boneyard Creek in Urbana between Lincoln Avenue and Confluence with Saline Branch, Condition of May 1997 (Contiued).

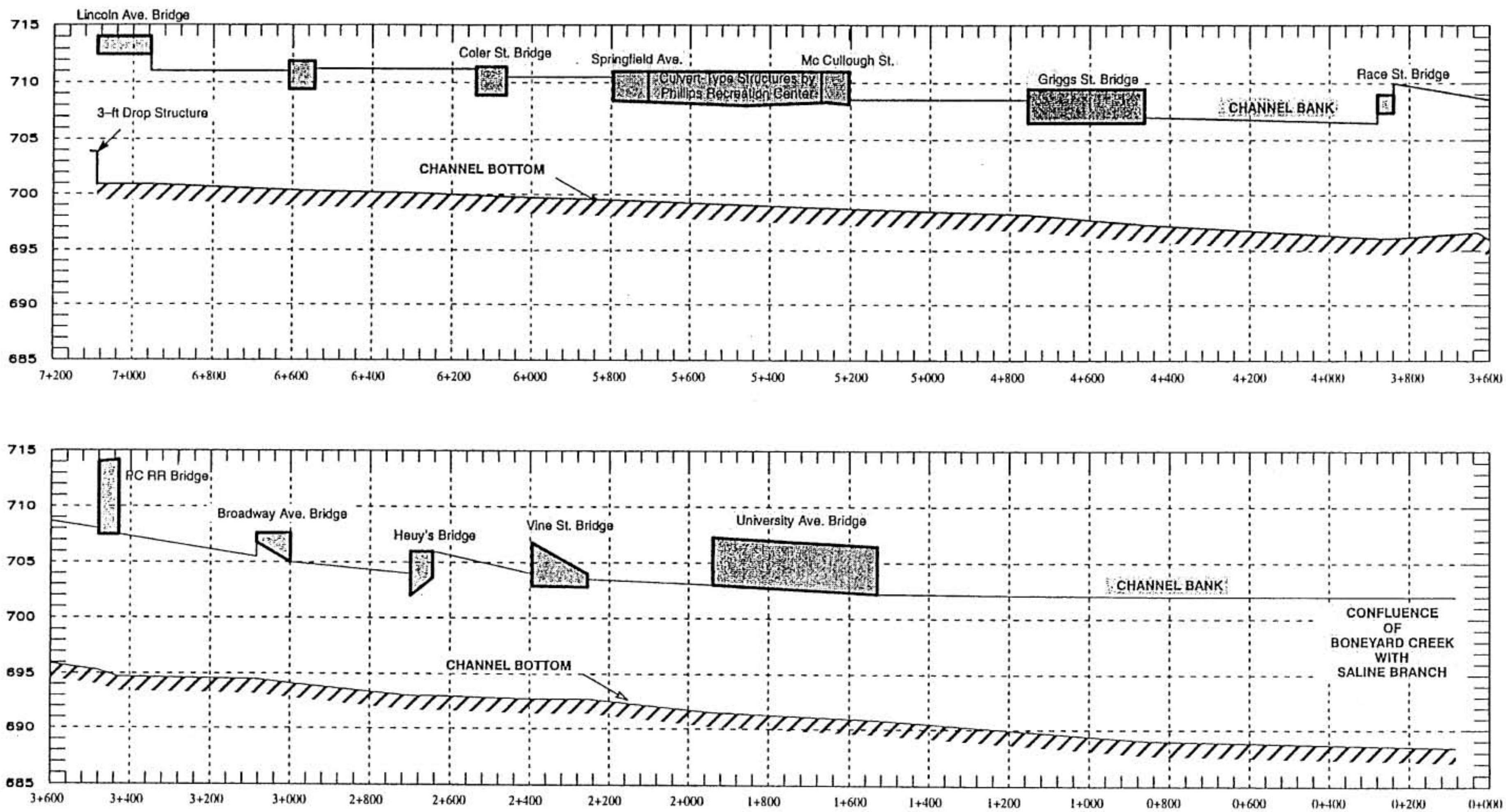

Fig. 2.3 Longitudinal Profile of Boneyard Creek in Urbana between Lincoln Avenue and Confluence with Saline Branch.

Table 2.3 Conditions of Channel Reaches of Boneyard Creek in Urbana between Lincoln Avenue and Confluence with Saline Branch.

LOCATION	REACH	STATION	REACH TYPE	LENGTH	ELEVATION				MANNING'S n	CHANNEL DESCRIPTION
					BED	BANK	LOW CHORD	UPPER CHORD		
U/S of Confluence with Saline Branch		0+085			688.4	702.0				
	1		OPEN CHANNEL	770					0.030-0.040	Earthen side slopes densely. Covered with trees
Urbana-Armory Footbridge		0+855			689.0	702.0				
	2		OPEN CHANNEL	675					0.030-0.040	Earthen side slope with vegetation.
D/S of University Ave. Bridge		1+530			690.8	702.2	702.2	706.5		Some riprap on sides close to bottom.
	3		BRIDGE	410					0.020	Twin box culverts. Each 12 ft width. x 13.4 ft height.
U/S of University Ave. Bridge		1+940			691.5	703.0	703.0			
	4		OPEN CHANNEL	315					0.025-0.030	Earthen side slopes with small vegetation.
D/S of Vine St. Bridge		2+255			692.7	703.5	702.8	704.0		
	5		BRIDGE	140					0.020	Twin box culverts each 12 ft width x 10.3 ft height.
U/S of Vine St. Bridge		2+395			692.7	704.0	702.9			
	6		OPEN CHANNEL	250					0.030	N. side made of Garvions. S. side earthen slope with trees
D/S of Huey's Bridge		2+645			693.0	706.0	703.6	706.0		
	7		BRIDGE	55					0.025	Concrete sides and bottom.
U/S of Huey's Bridge		2+700			693.0	704.0	702.0	706.0		
	8		OPEN CHANNEL	300					0.030	Garvions on S. side. N. side earthen with some vegetation
D/S of Broadway Ave. Bridge		3+000			694.1	705.0	705.0	707.6		
	9		BRIDGE	85					0.024	Box Culvert with 20 ft width and 11 ft height
U/S of Broadway Ave. Bridge		3+085			694.5	705.5	706.8	707.6		
	10		OPEN CHANNEL	345					0.035	Earthen sides with vegetation (trees).
D/S of PC RR Bridge		3+430			694.7	707.5	707.5	714.2		Stones in channel bottom.
	11		BRIDGE	50					0.020	Twin box culvert, each 15.2 ft width and 11.5 ft height
U/S of PC RR Bridge		3+480			695.3	708.0	707.5	714.0		
	12		OPEN CHANNEL	120					0.035	Sheet piling starts DS of Race St. Bridge
D/S of Race St. Bridge		3+600			695.9	713.6	710.2	713.7		
	13		BRIDGE	30					0.030	Sheet piling side and concrete bottom
U/S of Race St. Bridge		3+630			696.5	710.2	710.2	713.7		
	14		OPEN CHANNEL	210					0.024	Sheet piling side and concrete bottom
D/S of Griggs St. Bridge		3+840			696.0	710.0	707.4	709.0		
	15		BRIDGE	40					0.024	Sheet piling continuous upstream
U/S of Griggs St. Bridge		3+880			696.0	706.5	707.4	709.0		
	16		OPEN CHANNEL	585					0.025	Sheet piling side and concrete bottom
D/S of Main St. Bridge		4+465			697.2	707.0	706.5	709.5		
	17		BRIDGE	290					0.024	Sheet piling side and concrete bottom
U/S of Main St. Bridge		4+755			698.1	708.5	706.5	709.5		
	18		OPEN CHANNEL	450					0.030	Sheet piling side and concrete bottom
D/S of Mc Cullough St. Bridge		5+205			698.6	708.5	708.11	711.0		
	19a		BRIDGE	55					0.024	Sheet piling side and concrete bottom
U/S of Mc Cullough St.Bridge		5+260			698.7		708.3	711.0		
	19b		CULVERTLIKE	200					0.024	Box Culvert
200-Foot Concrete Tunnel		5+460			699.0		708.0	711.0		
	19c		CULVERTLIKE	240					0.030	Sheet piling with precast concrete deck ceiling
D/S of Springfield Ave. Bridge		5+700			699.3		708.3	711.0		
	19d		BRIDGE	95					0.024	Sheet piling side and concrete bottom
U/S of Springfield Ave.Bridge		5+795			699.4	710.5	708.4	711.0		
	20		OPEN CHANNEL	270					0.024	Sheet piling side and concrete bottom
D/S of Coler Ave. Bridge		6+065			699.7	710.5	708.9	711.4		
	21		BRIDGE	75					0.024	Sheet piling side and concrete bottom
U/S of Coler Ave. Bridge		6+140			699.8	711.2	708.9	711.4		
	22		OPEN CHANNEL	145					0.030	Sheet piling side and concrete bottom
12.5x7.5 ft Culvert		6+285			700.0	711.2				
	23		OPEN CHANNEL	260					0.030	Sheet piling side and concrete bottom
D/S of Busey Ave. Bridge		6+545			700.2	711.2	709.4	711.9		
	24		BRIDGE	65					0.024	Sheet piling side and concrete bottom
U/S of Busey Ave. Bridge		6+610			700.3	711.0	709.4	711.9		
	25		OPEN CHANNEL	345					0.024	Sheet piling side and concrete bottom
W of Lincoln Ave. Bridge		6+955			700.8	711.0	712.5	714.0		
	26		BRIDGE	135					0.024	Sheet piling side and concrete bottom
3 foot Drop Structure at Lincoln Ave.		7+090			700.8	714.0	712.5	714.0		

note: In the Manning's n column, the first value is for the channel bottom, the second for the banks.

3. HYDRAULIC PERFORMANCE GRAPHS FOR STUDIED REACHES

A channel system usually shows reachwise variations of the geometry, wall roughness and alignment. In addition, some reaches have no restriction to always flow as open channels, whereas others may shift from open-channel flow conditions to surcharged conditions under high flow; this is the case of closing-top reaches of the creek. Moreover, discharge variation along the channel due to outflow from sewers draining the local areas is usually observed. To account for these factors in the hydraulic analysis of a channel system it is necessary to divide the system into reaches. Thus, the reaches should be chosen such that, within each reach, the channel properties are approximately the same, the discharge variation due to lateral flow contributions does not change significantly, and the flow conditions are similar.

In this study the hydraulic capacity of the Boneyard in Urbana is evaluated with the method of Hydraulic performance graph introduced by Yen and González (1994). The procedure to establish the hydraulic performance graph (***HPG***) for an open-channel reach is given in Appendix B. The channel reaches into which the portion of the Boneyard Creek between its confluence with Saline Branch and Lincoln Avenue was divided in this study are listed in Table 2.3. For the purpose of this study, the culvert-like structure by the Phillips Recreation Center, was divided into 4 reaches, based on the detailed survey conducted by Bernes, Clancy and Associates in 1995, as indicated in Chapter 2. Among the 29 reaches shown in Fig. 2.2 and described in Table 2.3, 14 are open-channel-type, and fifteen, including 13 street bridges and two culvertlike reaches, are closing-top-type.

3.1 *HPG's* and Rating Curves for Individual Reaches

The set of the ***HPG's*** and rating curves (if applicable) for each of the 29 reaches of the portion of the Boneyard Creek between Confluence and Lincoln Avenue for the May-1997 channel condition is presented in Figs 3.1 to 3.26. In the ***HPG*** there are three characteristic lines. The **Z-line** represents horizontal water surface along the channel reach, the **N-line** denotes normal (steady uniform) flow, and the **C-curve** indicates flow with critical depth at the exit (channels with non-steep slope) or at the entrance (channels with steep slope) of the reach. The ***HPG***'s are constructed in discharge increments of either 100 or 200 cfs, within the elevations range of non-flooding open-channel flow conditions in the reach, by using the method described in Appendix B of Yen and González (1995). The rating curves of the 14 closing-top reaches were constructed considering the flow as flow through closed conduits accounting for the friction losses, as well as for entrance and exit losses.

3.2 Hydraulic Capacities of Individual Reaches

As defined by Yen and González (1994), the absolute maximum carrying capacity of a channel reach (***Qamax***) is the largest discharge which the reach is able to convey without bank overflow when the water depth at its exit station is critical and the maximum uniform flow capacity (***Qnmax***) is the maximum steady-uniform-flow discharge that the reach can convey either as the flow is just about to spill overbank, or to become pressurized if the reach is of the closing-top type. For closing-top reaches they defined the maximum surcharged-flow capacity (***Qsmax***) as the discharge under pressurized conduit flow condition that a reach can convey when the upstream water surface is at the bankfull stage and the downstream water elevation is at the crown level of the bridge or culvert opening. The water surface profiles corresponding to these three different capacities together with the surface profile for the capacity with an intermediate exit water level are shown in Fig. 3.12 as an example of an open-channel reach, and in Fig. 3.13 for a closing-top reach. It should be clear that the hydraulic capacity of a reach is not unique but dependent on the downstream exit water level.

The values of ***Qamax*** and ***Qnmax*** for the reaches can be read from their individual ***HPG***. These values and the computed values of ***Qsmax*** for the reaches into which the Boneyard in Urbana has been divided in the present study are presented in Table 3.1. It can be observed that for all the closing-top reaches, but reach 19a, ***Qnmax*** < ***Qsmax***. The maximum capacities do not increase orderly reach by reach towards downstream. Those with low ***Qamax*** and ***Qnmax*** are potential bottlenecks causing flooding in the drainage system.

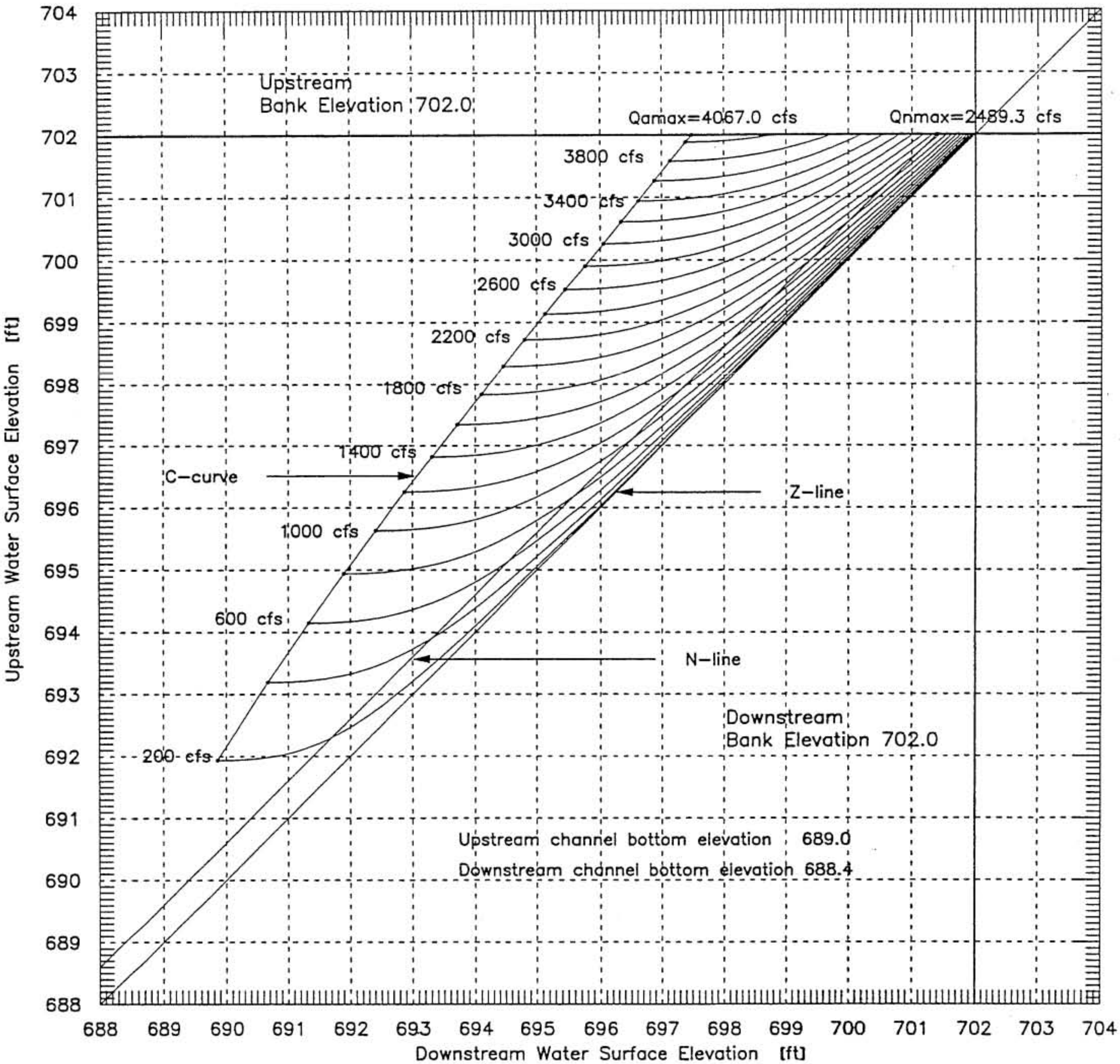

Fig. 3.1 HPG for Reach 1 (Confluence with Saline Branch to Urbana Armory Footbridge from Sta 0+085 to Sta 0+855).

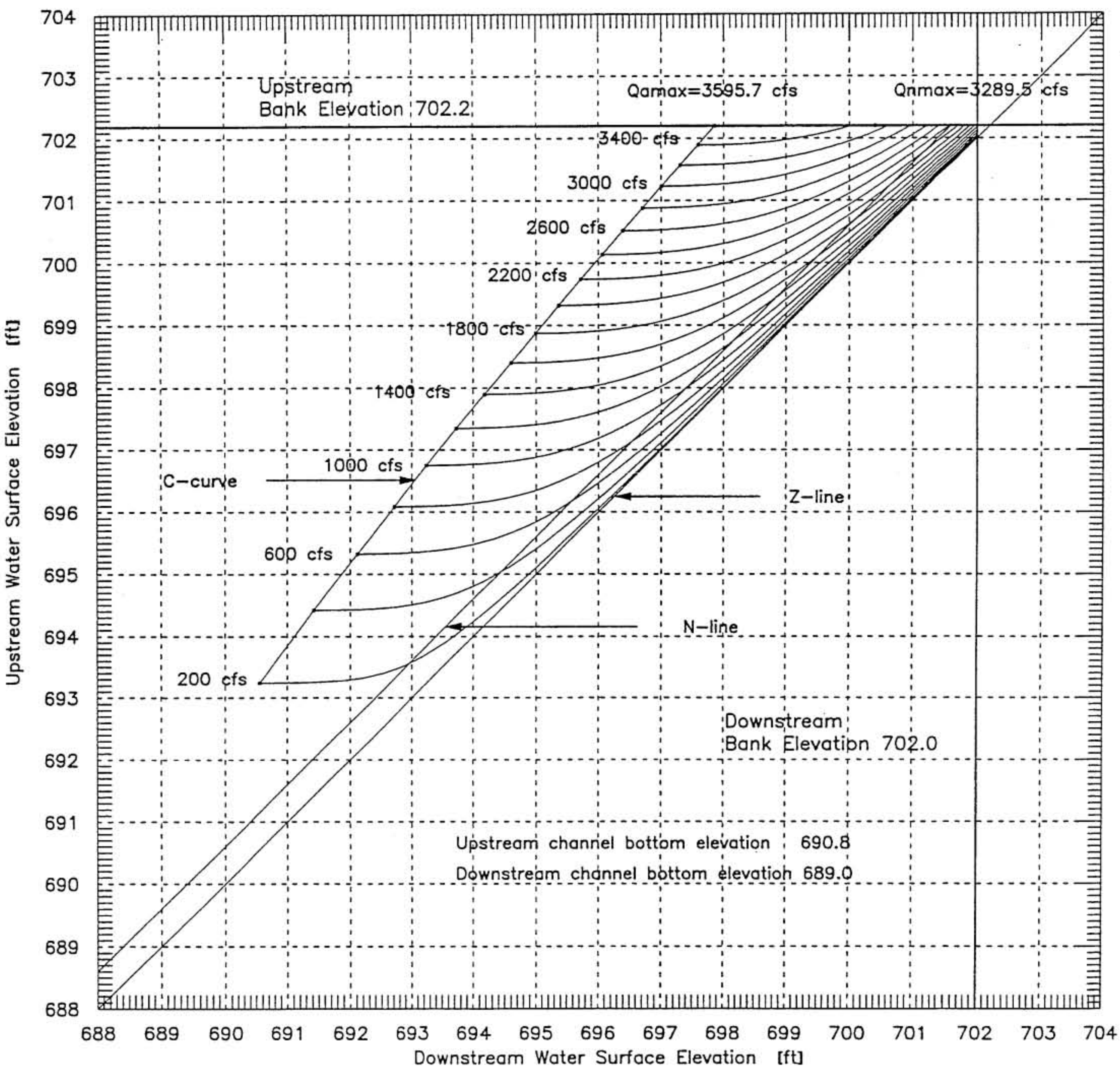

Fig. 3.2 HPG for Reach 2 (Urbana Armory Footbridge to D/S of University Ave. Bridge, from Sta 0+855 to Sta 1+530).

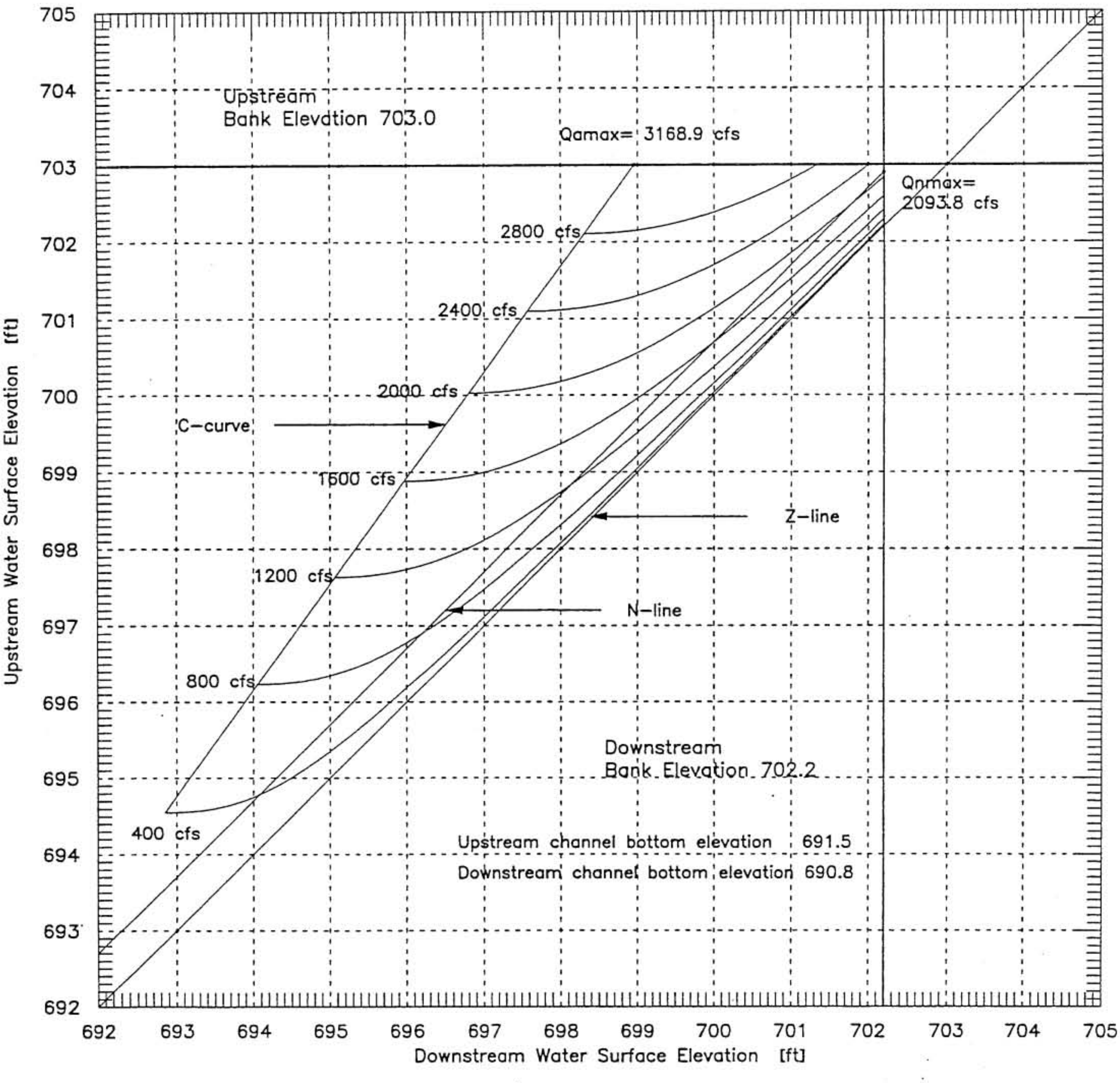

Fig. 3.3*a* HPG for Reach 3 (University Ave. Bridge, from Sta 1+530 to Sta 1+940).

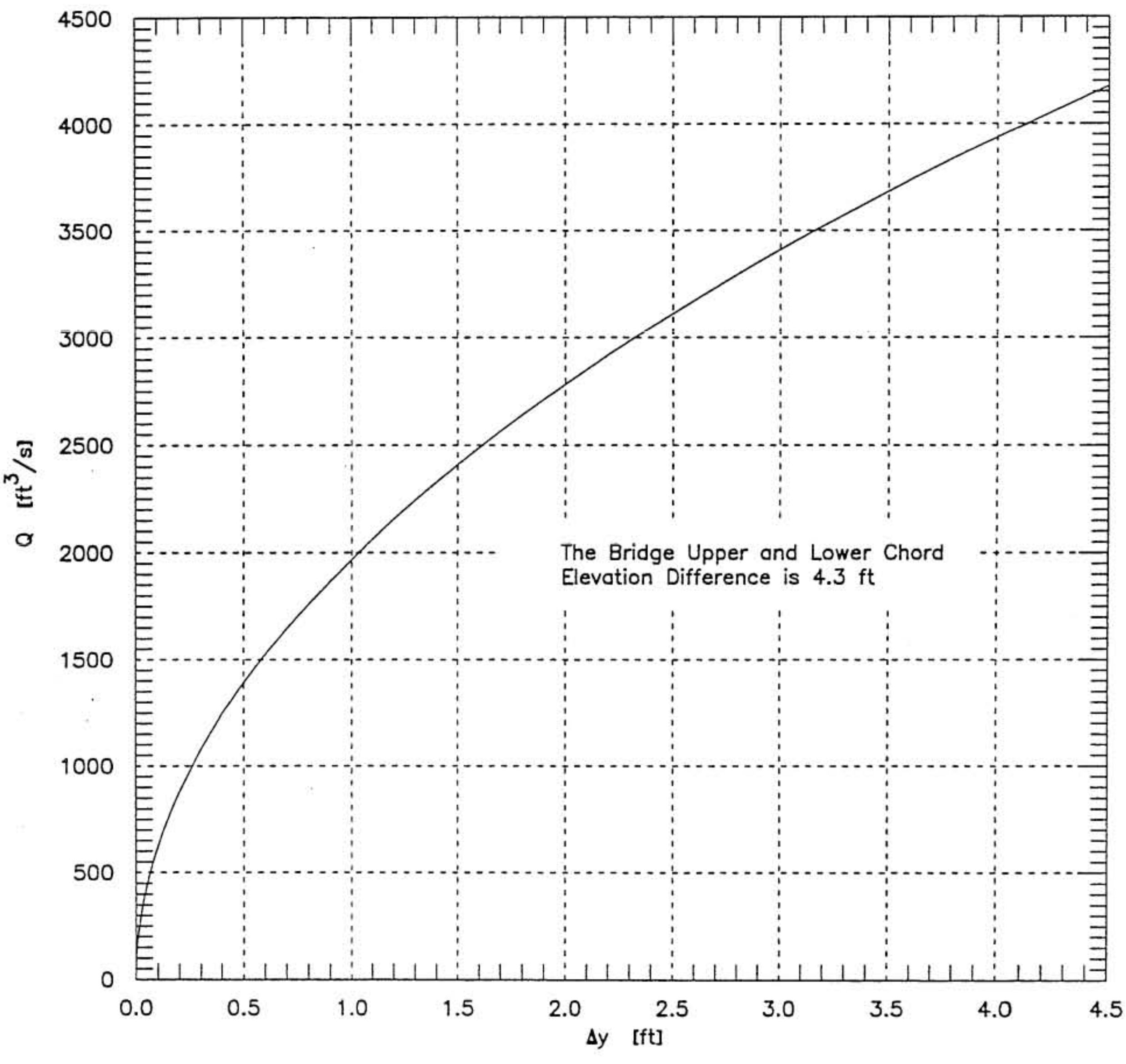

Fig. 3.3*b* Rating Curve for Reach 3 (University Ave. Bridge, from Sta 1+530 to Sta 1+940).

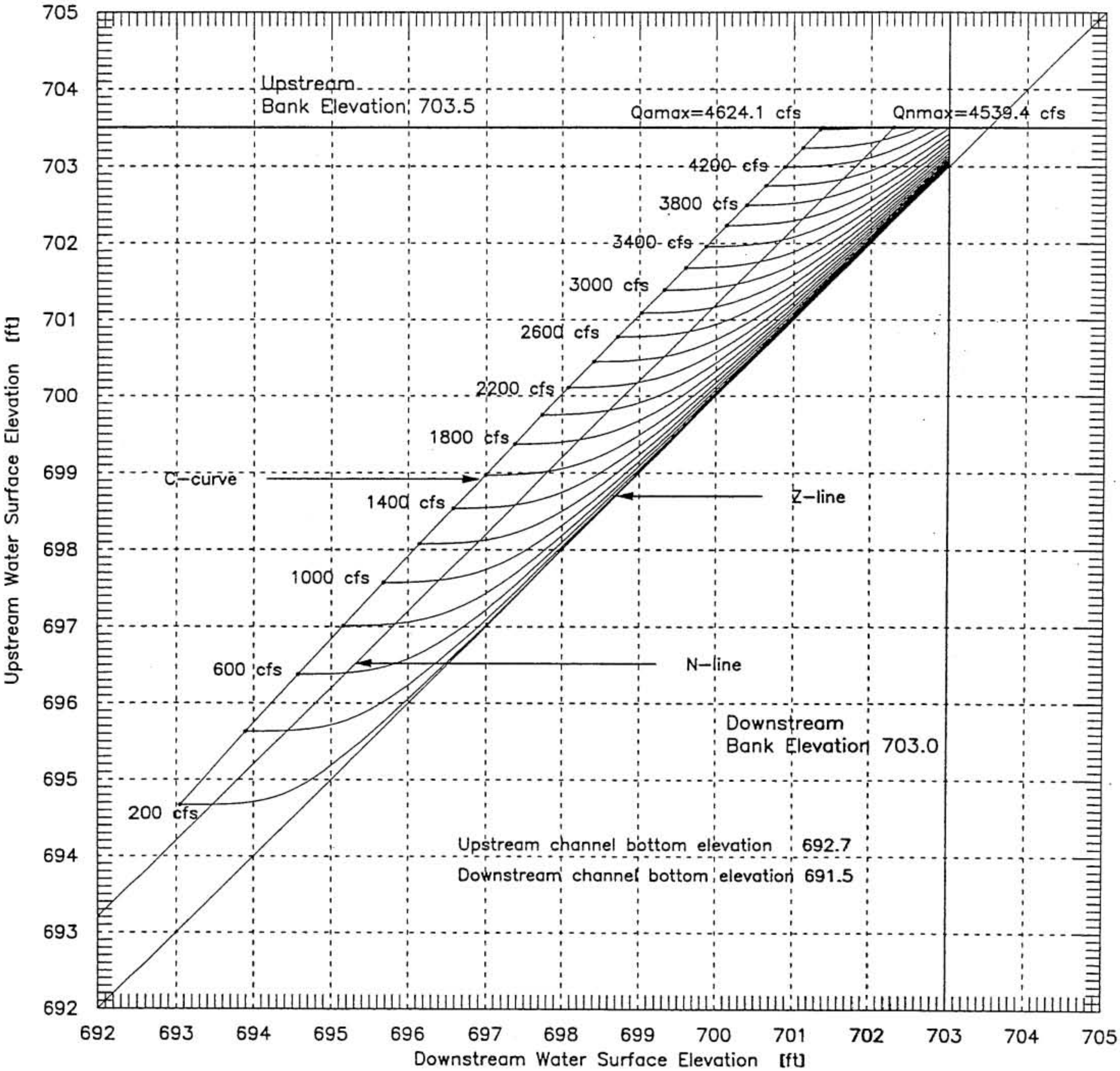

Fig. 3.4 HPG for Reach 4 (U/S of University Ave. Bridge to D/S of Vine St. Bridge from Sta 1+940 to Sta 2+255).

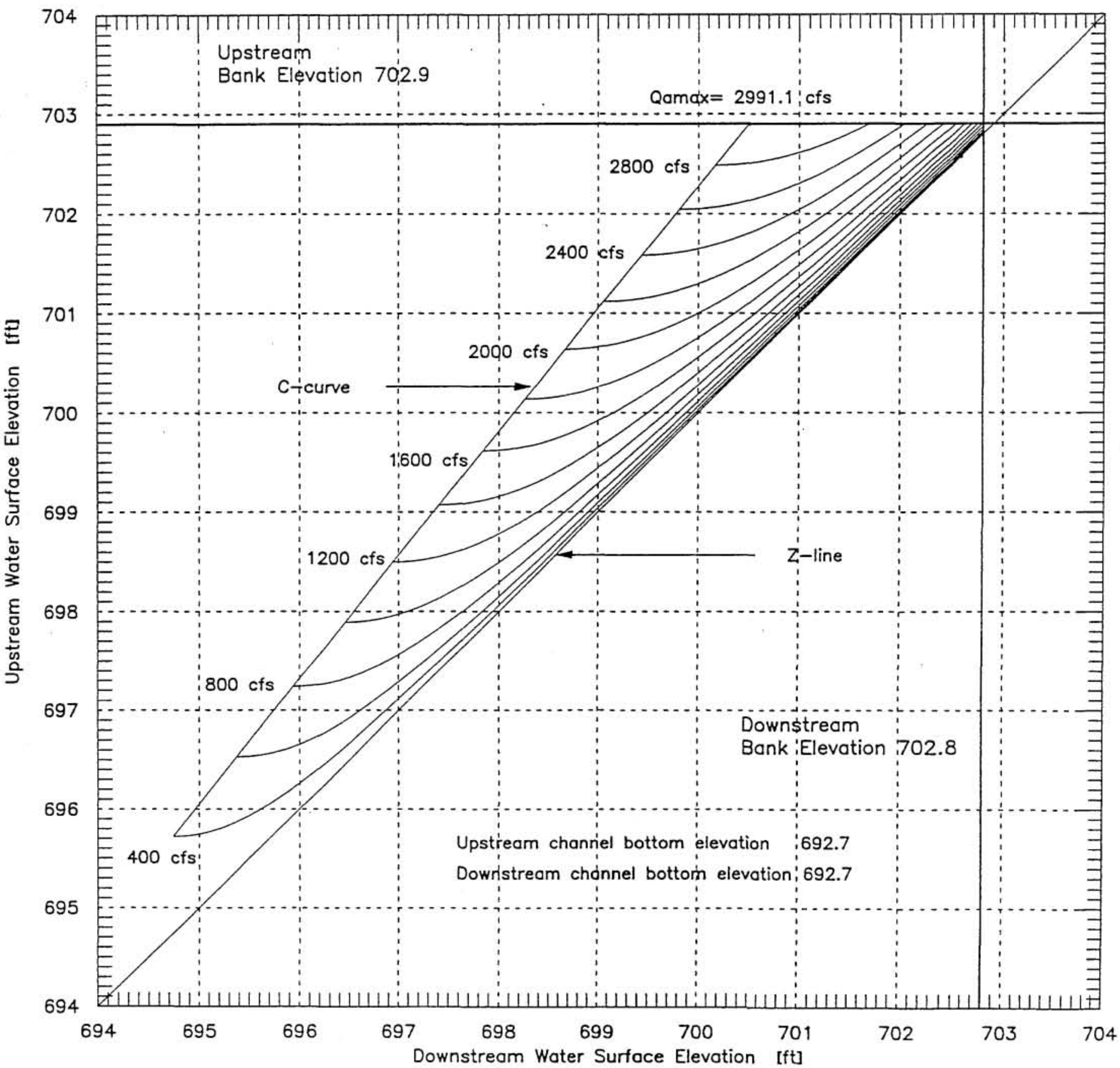

Fig. 3.5*a* HPG for Reach 5 (Vine St. Bridge from Sta 2+255 to Sta 2+395).

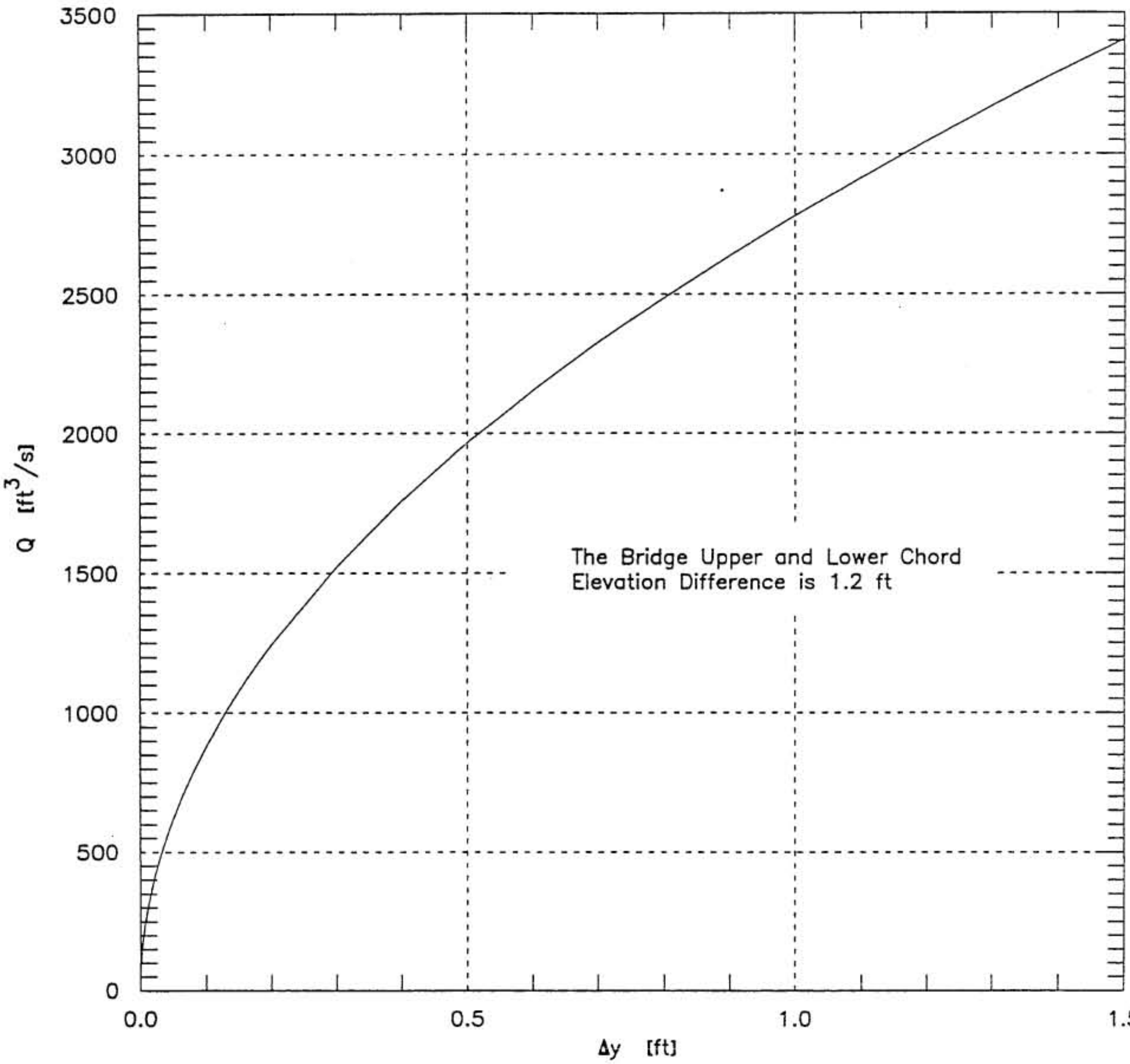

Fig. 3.5*b* Rating Curve for Reach 5 (Vine St. Bridge from Sta 2+255 to Sta 2+395).

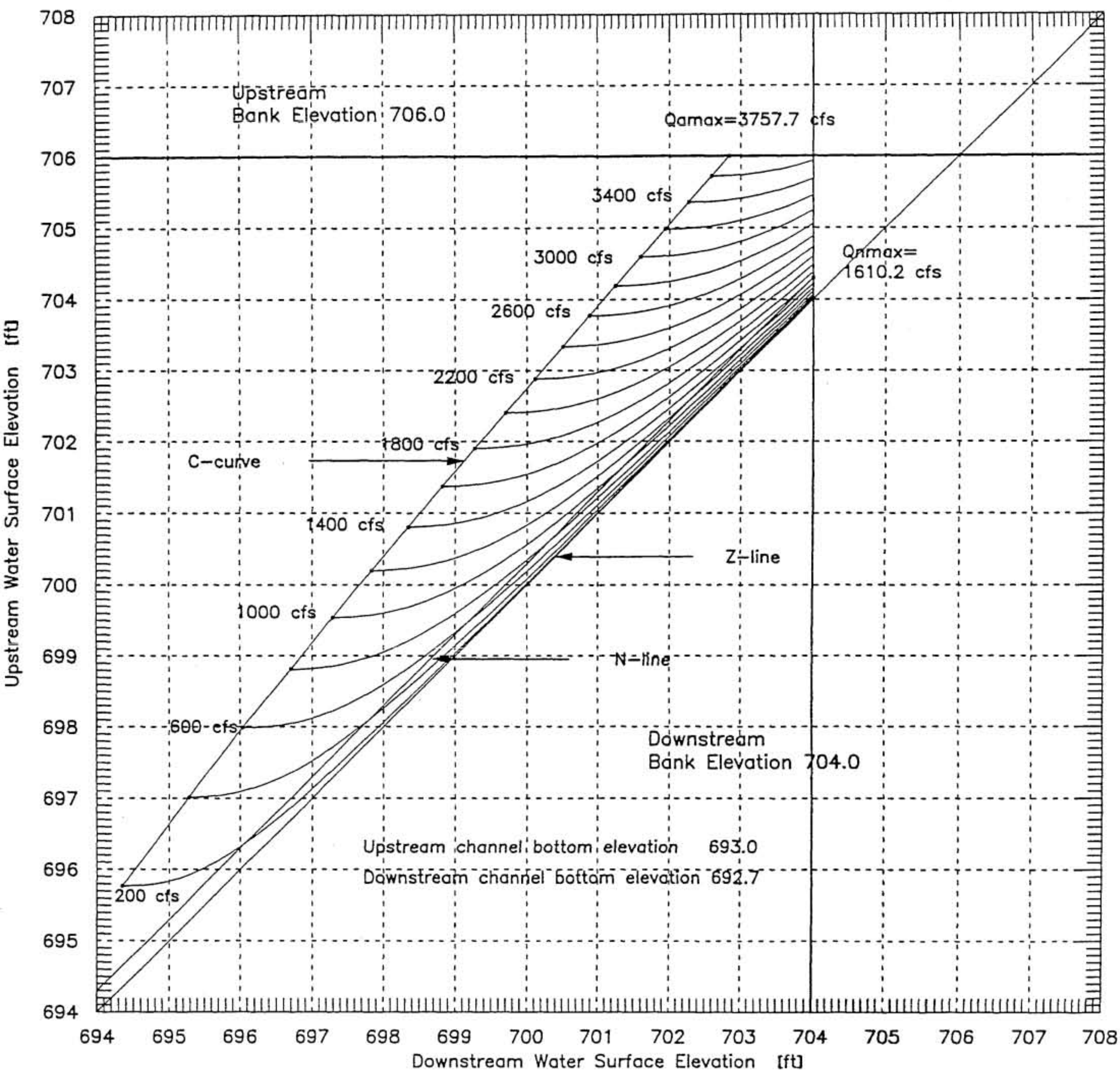

Fig. 3.6 HPG for Reach 6 (U/S of Vine St. Bridge to D/S of Huey's Bridge from Sta 2+395 to Sta 2+645).

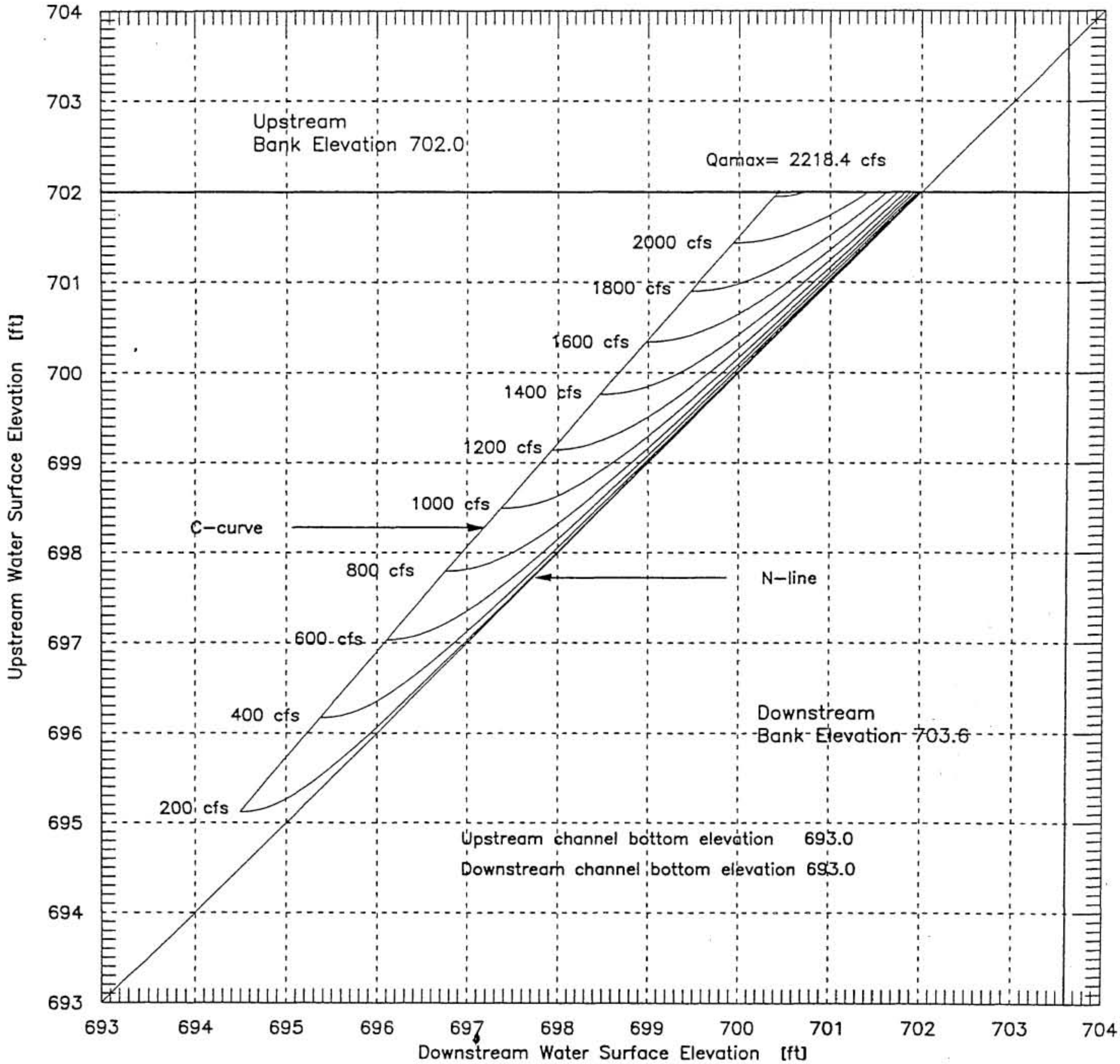

Fig. 3.7*a* HPG for Reach 7 (Huey's Bridge from Sta 2+645 to Sta 2+700).

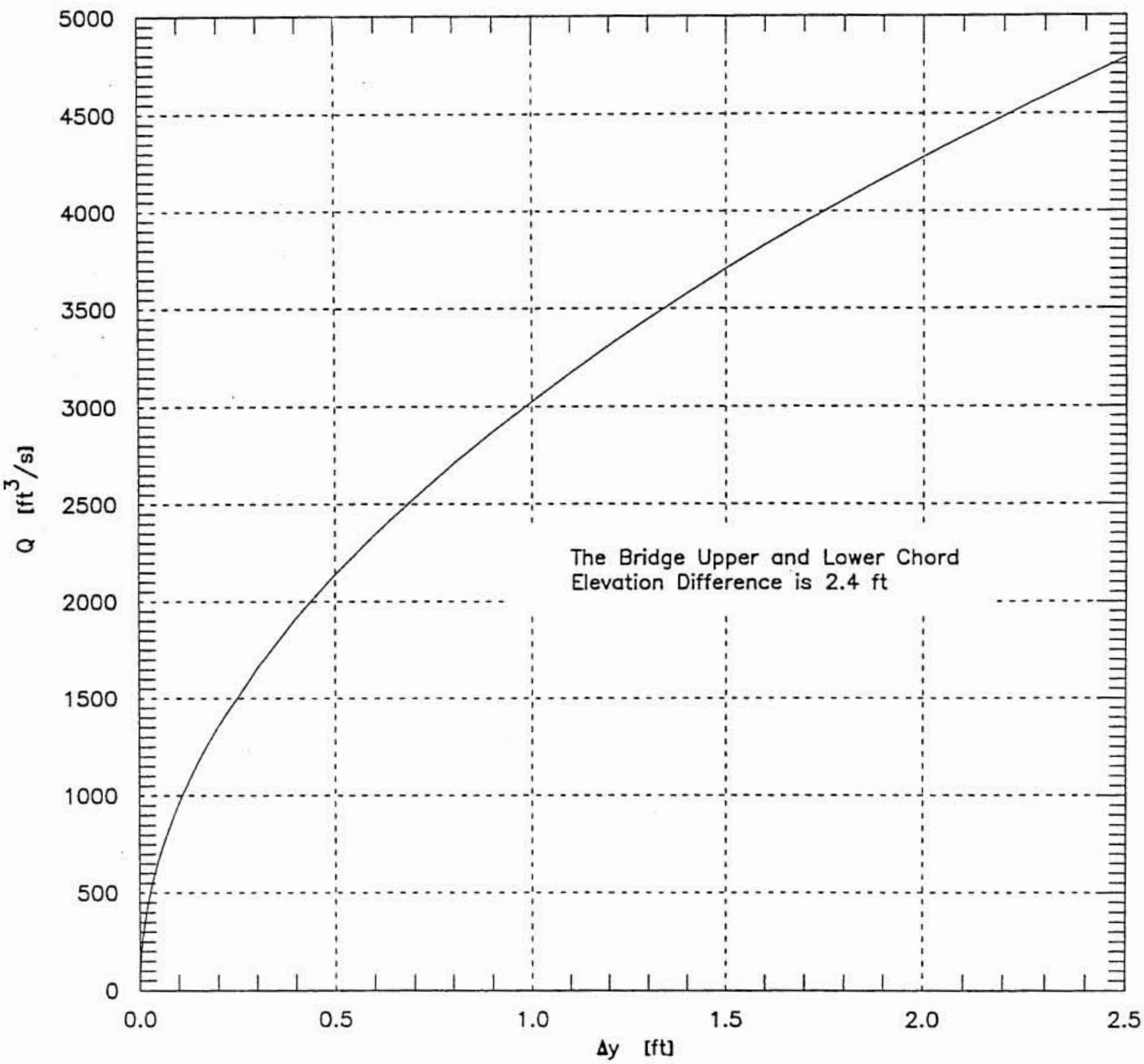

Fig. 3.7*b* Rating Curve for Reach 7 (Huey's Bridge from Sta 2+645 to Sta 2+700).

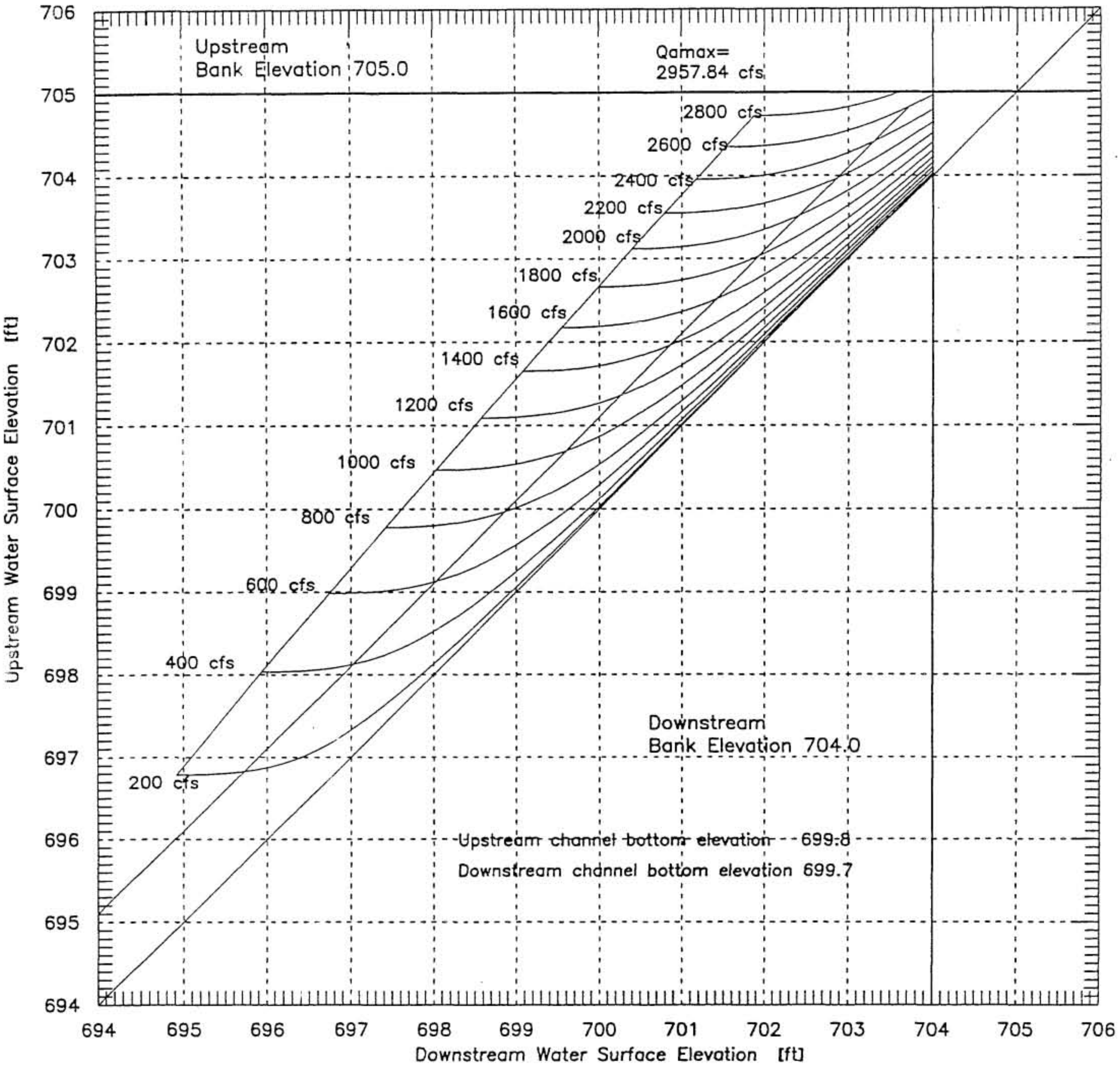

Fig. 3.8 HPG for Reach 8 (U/S of Huey's Bridge to D/S of Broadway Ave. Bridge from Sta 2+700 to Sta 3+000).

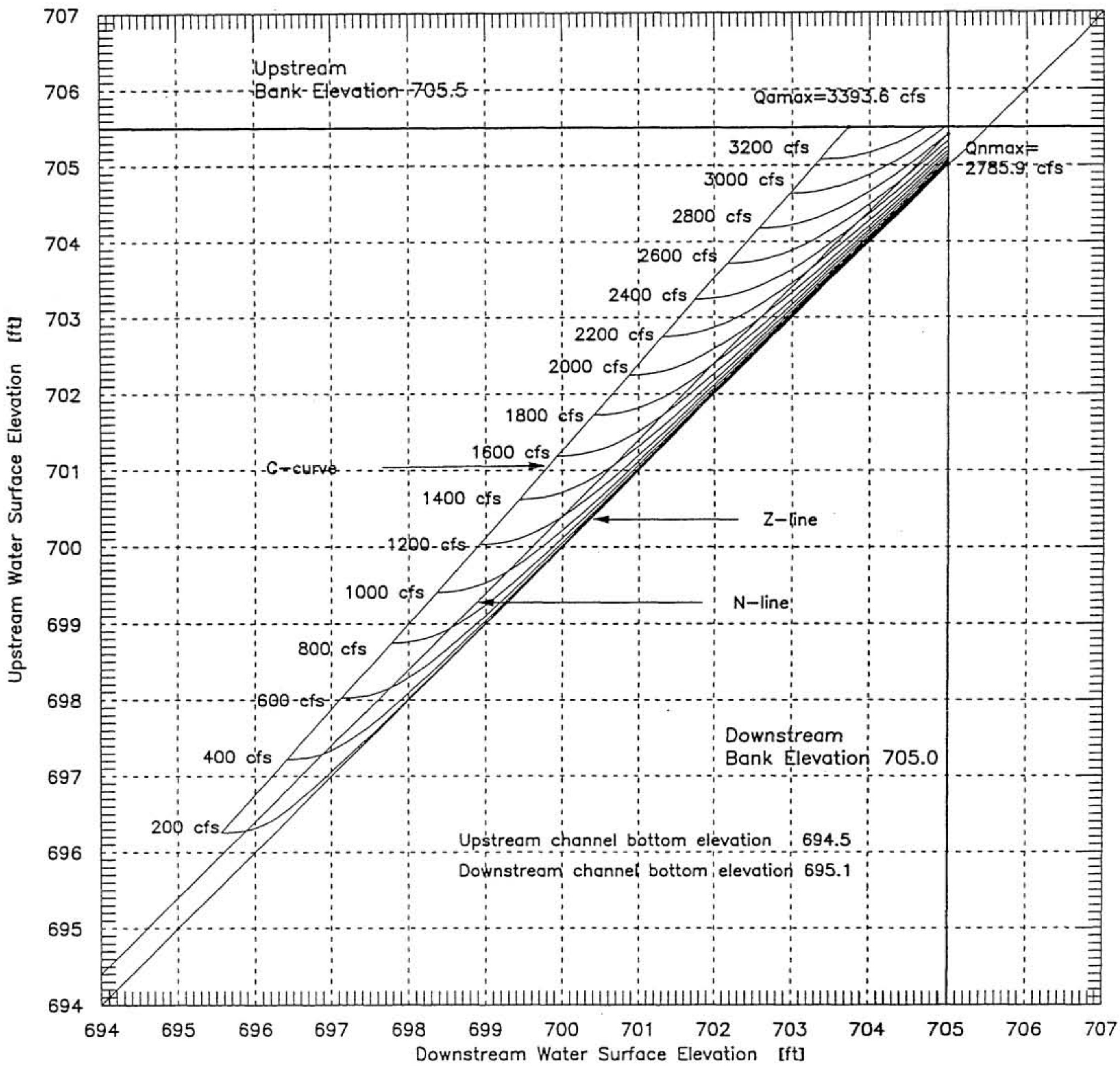

Fig. 3.9*a* HPG for Reach 9 (Broadway Ave. Bridge from Sta 3+000 to Sta 3+085).

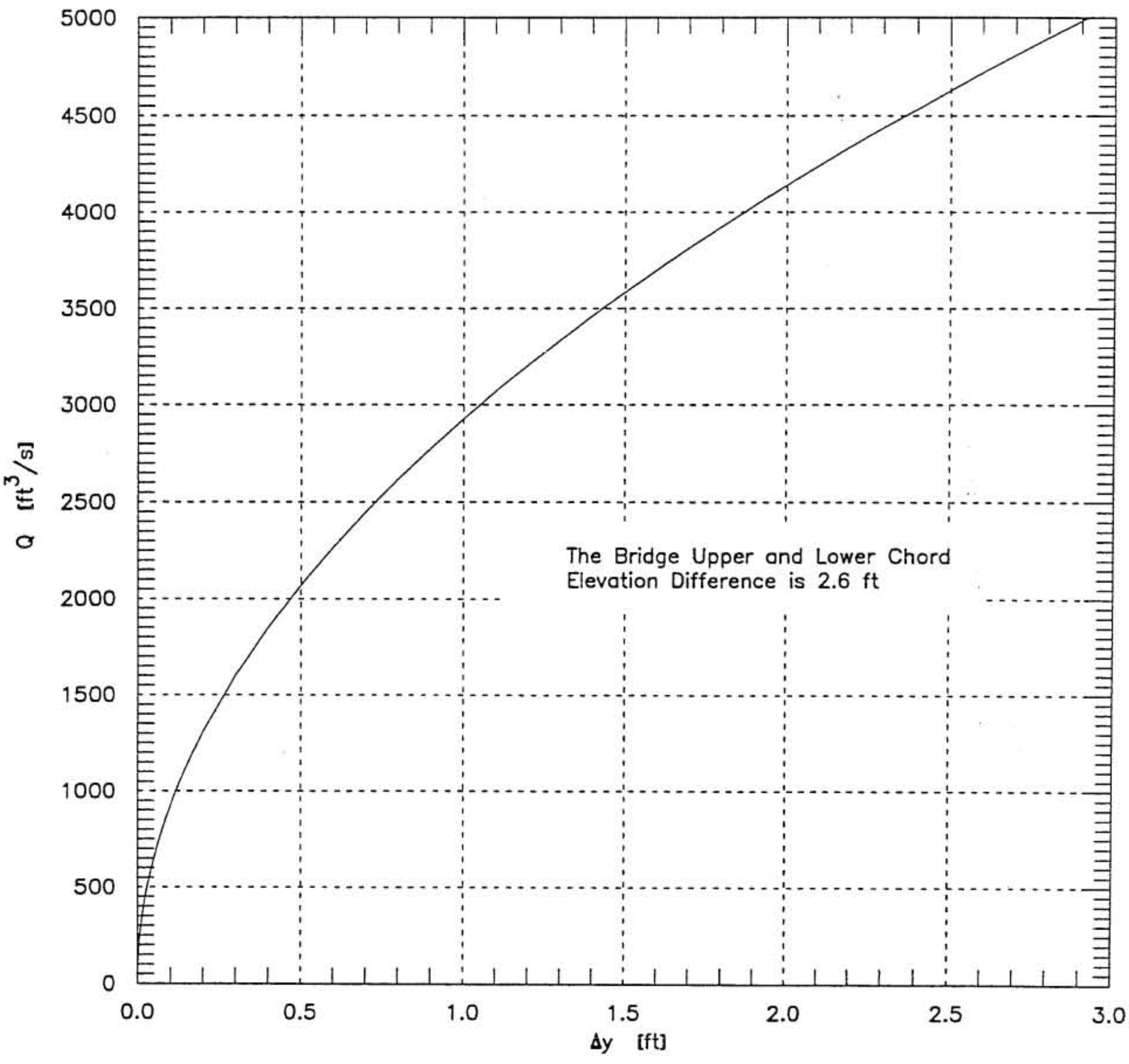

Fig. 3.9*b* Rating Curve for Reach 9 (Broadway Ave. Bridge from Sta 3+000 to Sta 3+085).

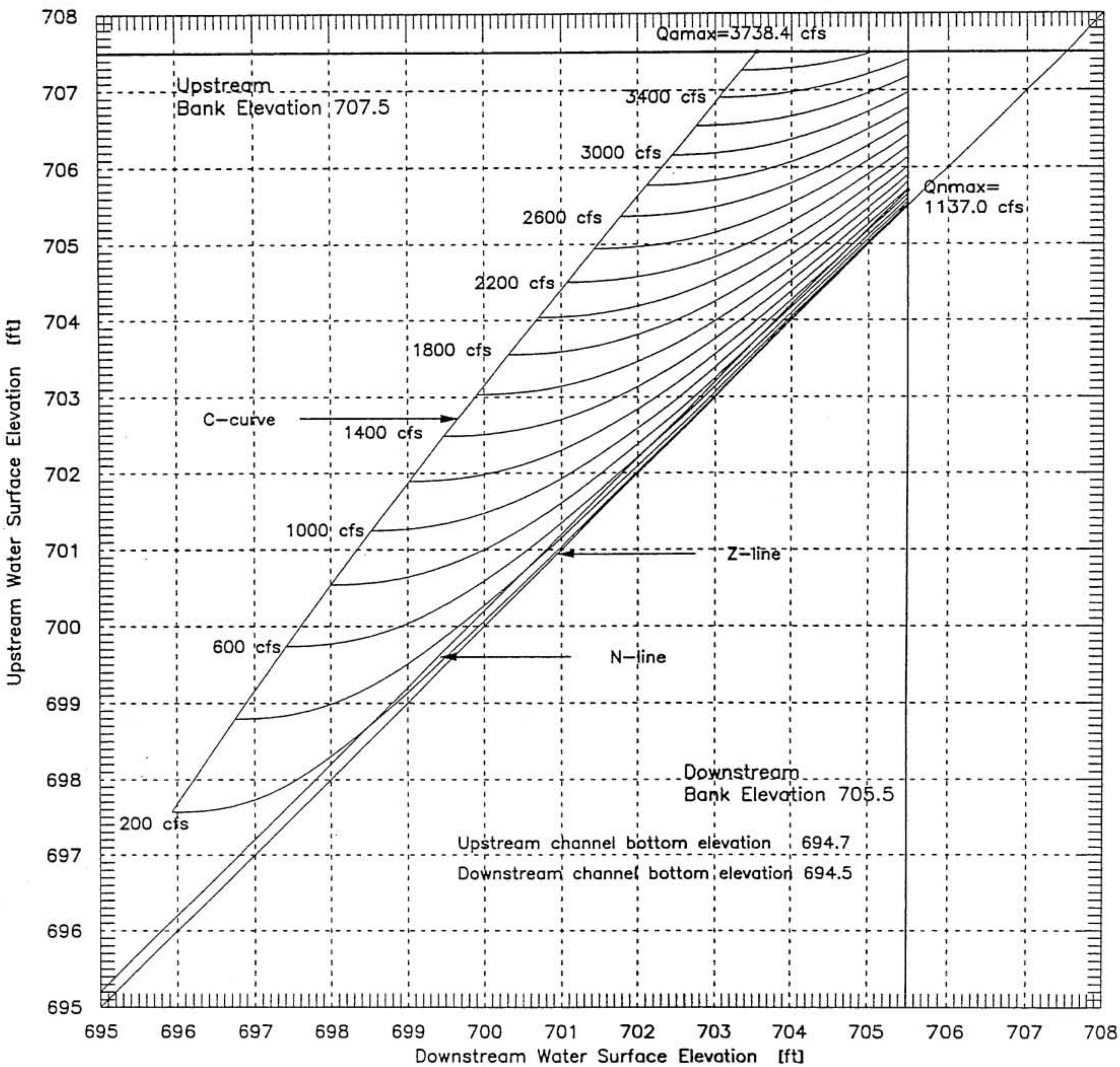

Fig. 3.10 HPG for Reach 10 (Broadway Ave. Bridge at Sta 3+085 to Sta 3+430).

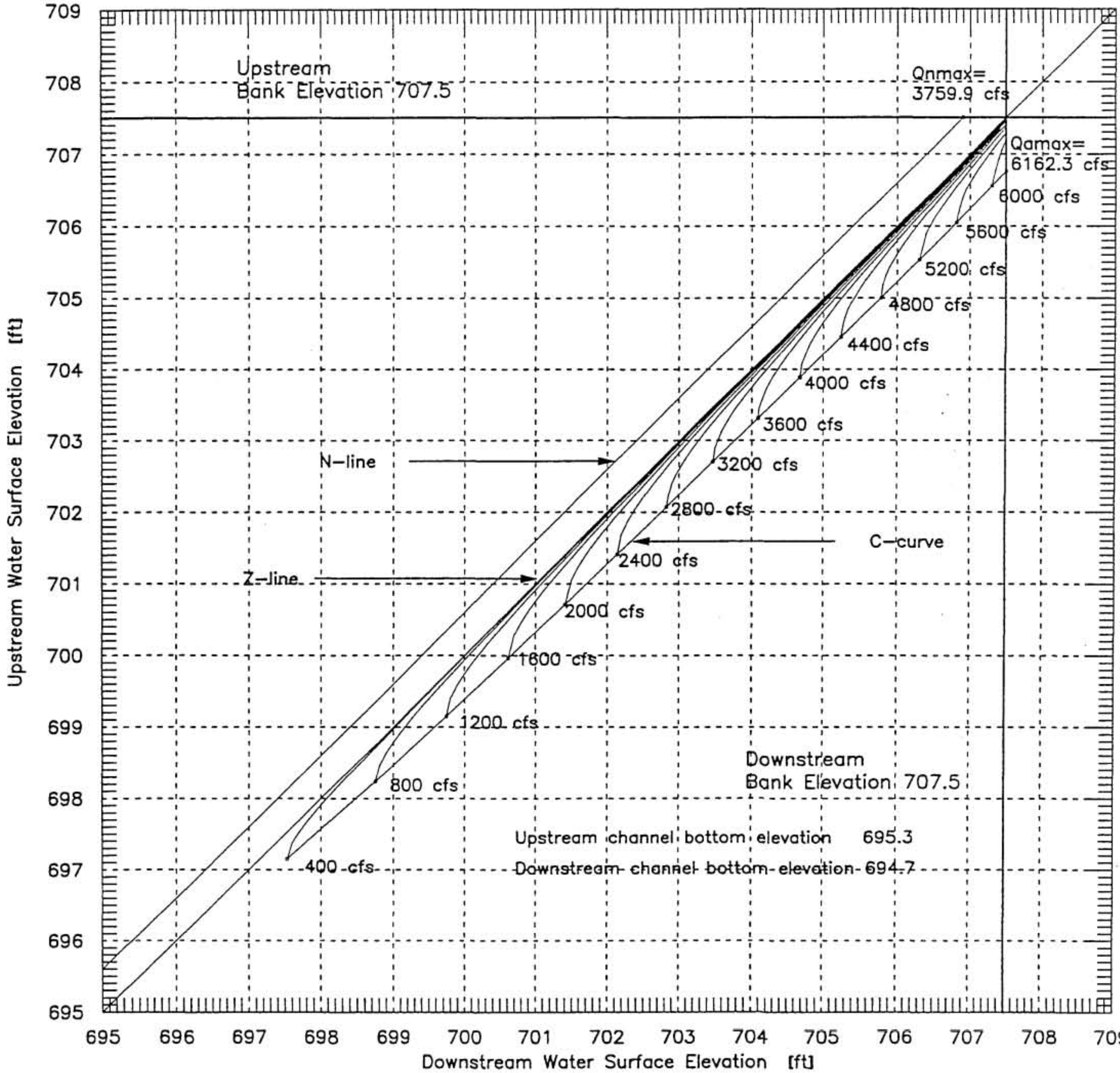

Fig. 3.11*a* HPG for Reach 11 (PC RR Bridge from Sta 3+430 to Sta 3+480).

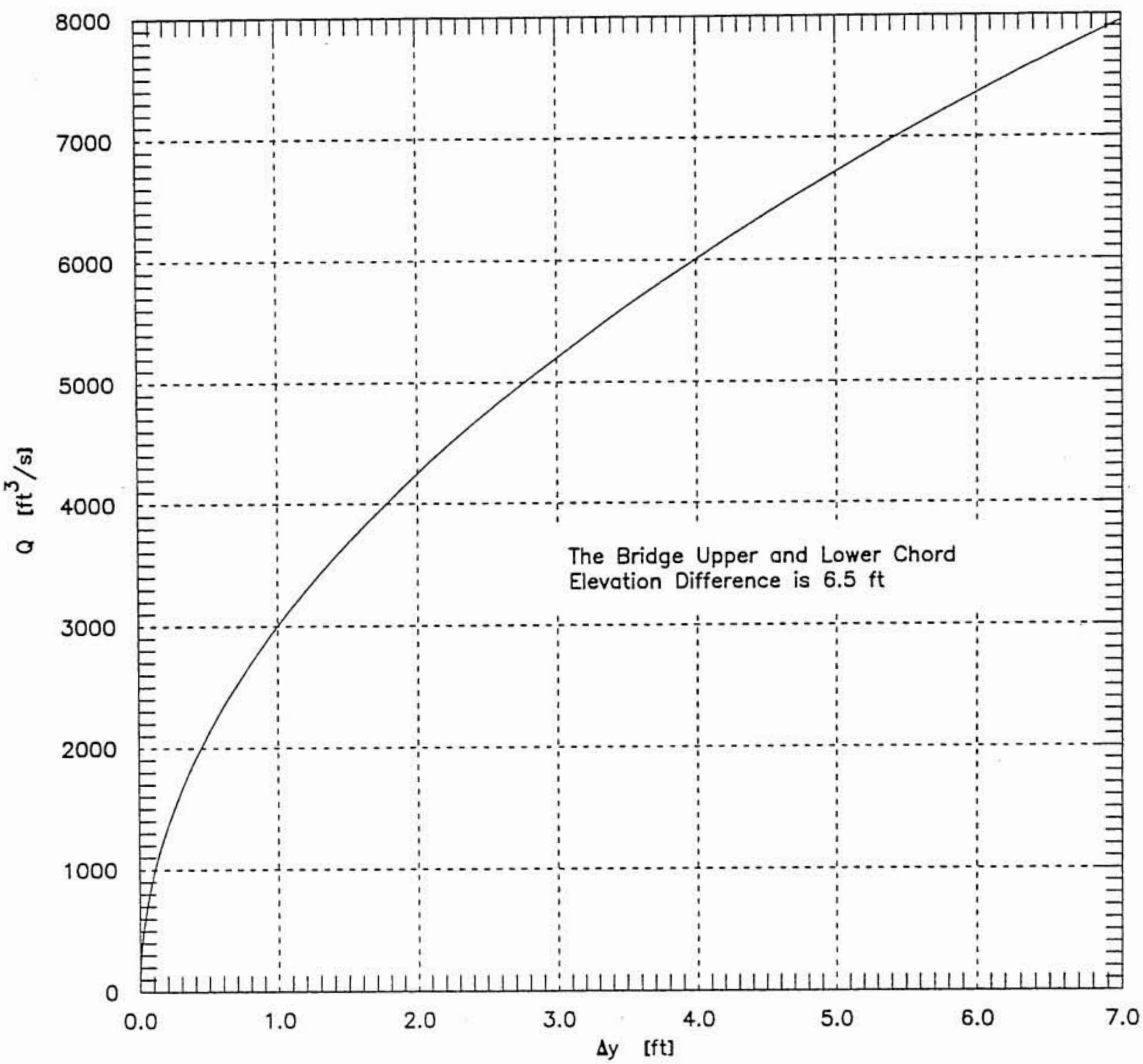

Fig. 3.11*b* Rating Curve for Reach 11 (PC RR Bridge from Sta 3+430 to Sta 3+480).

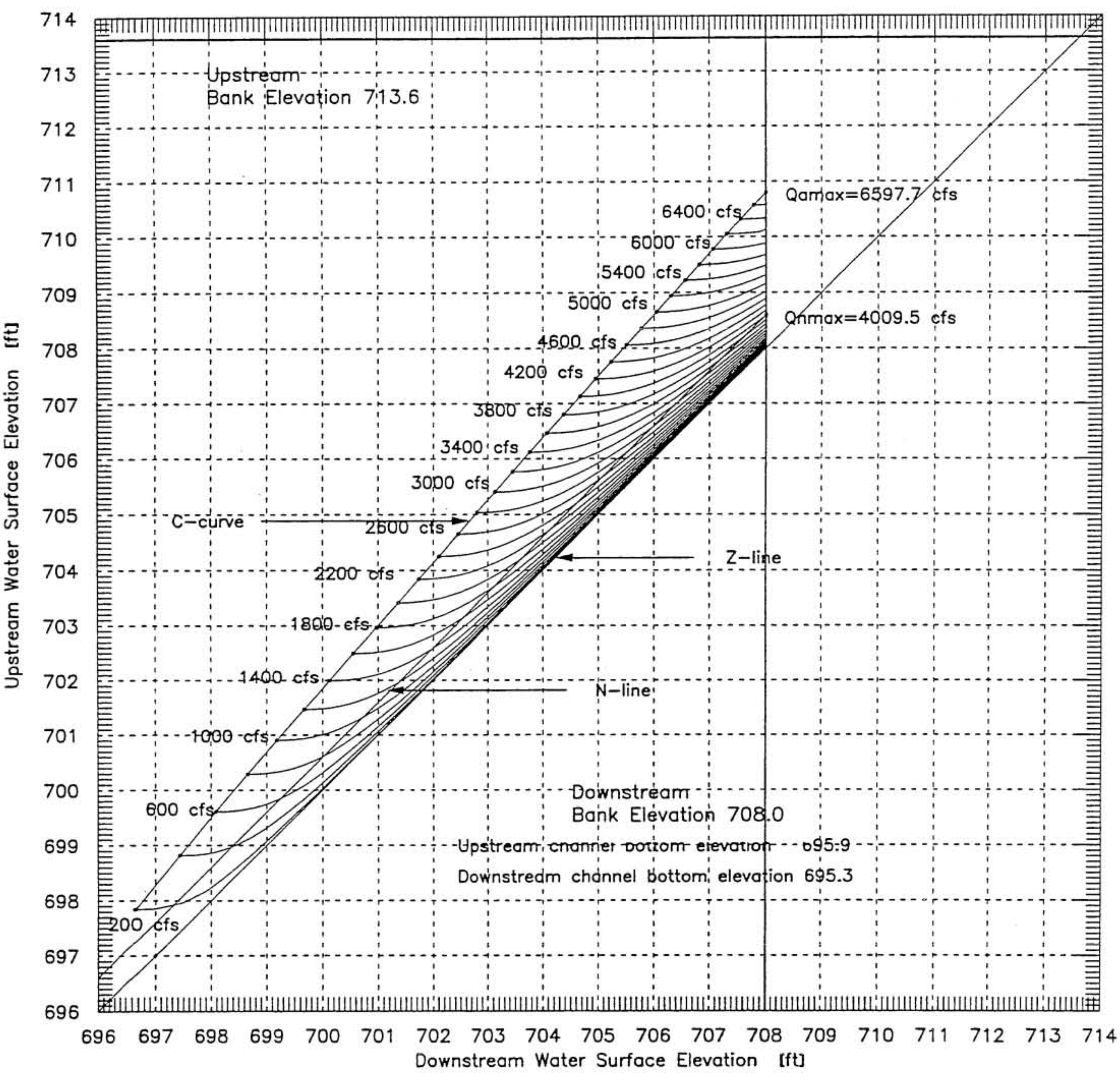

Fig. 3.12 HPG for Reach 12 (U/S of PC RR Bridge to D/S of Race St. Bridge from Sta 3+480 to Sta 3+600).

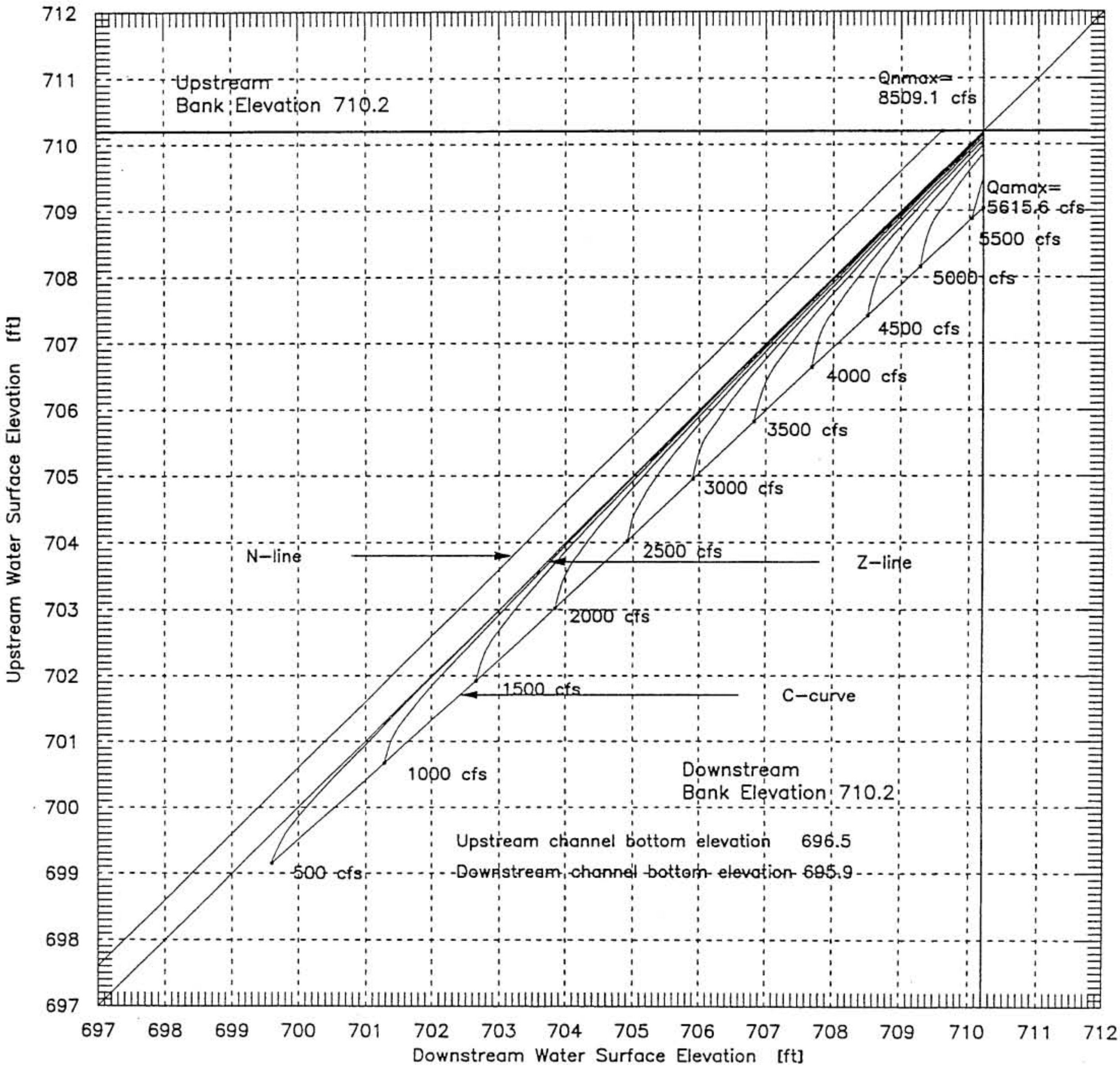

Fig. 3.13*a* HPG for Reach 13 (Race St. Bridge from Sta 3+600 to Sta 3+360).

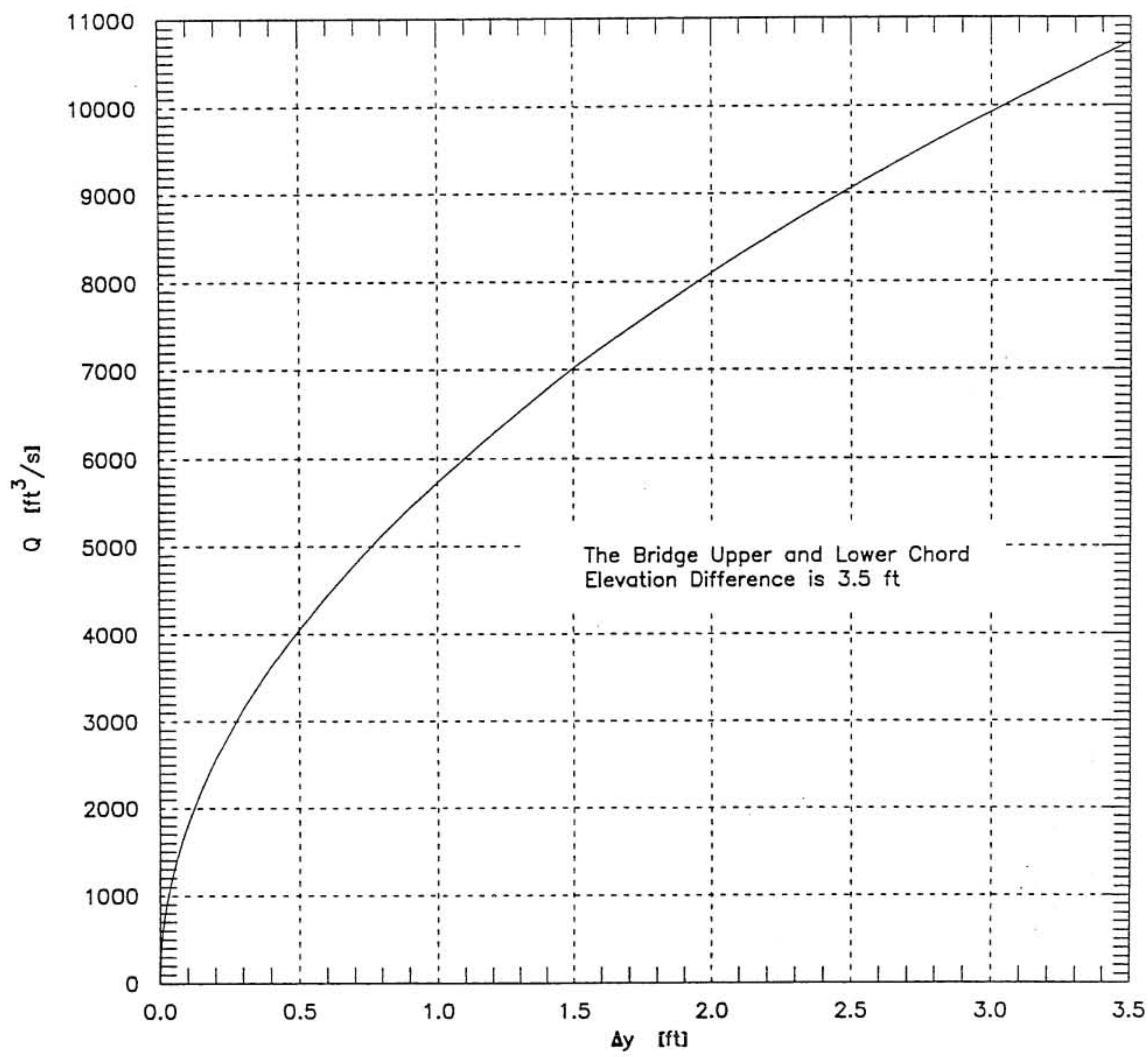

Fig. 3.13*b* Rating Curve for Reach 13 (Race St. Bridge from Sta 3+600 to Sta 3+360).

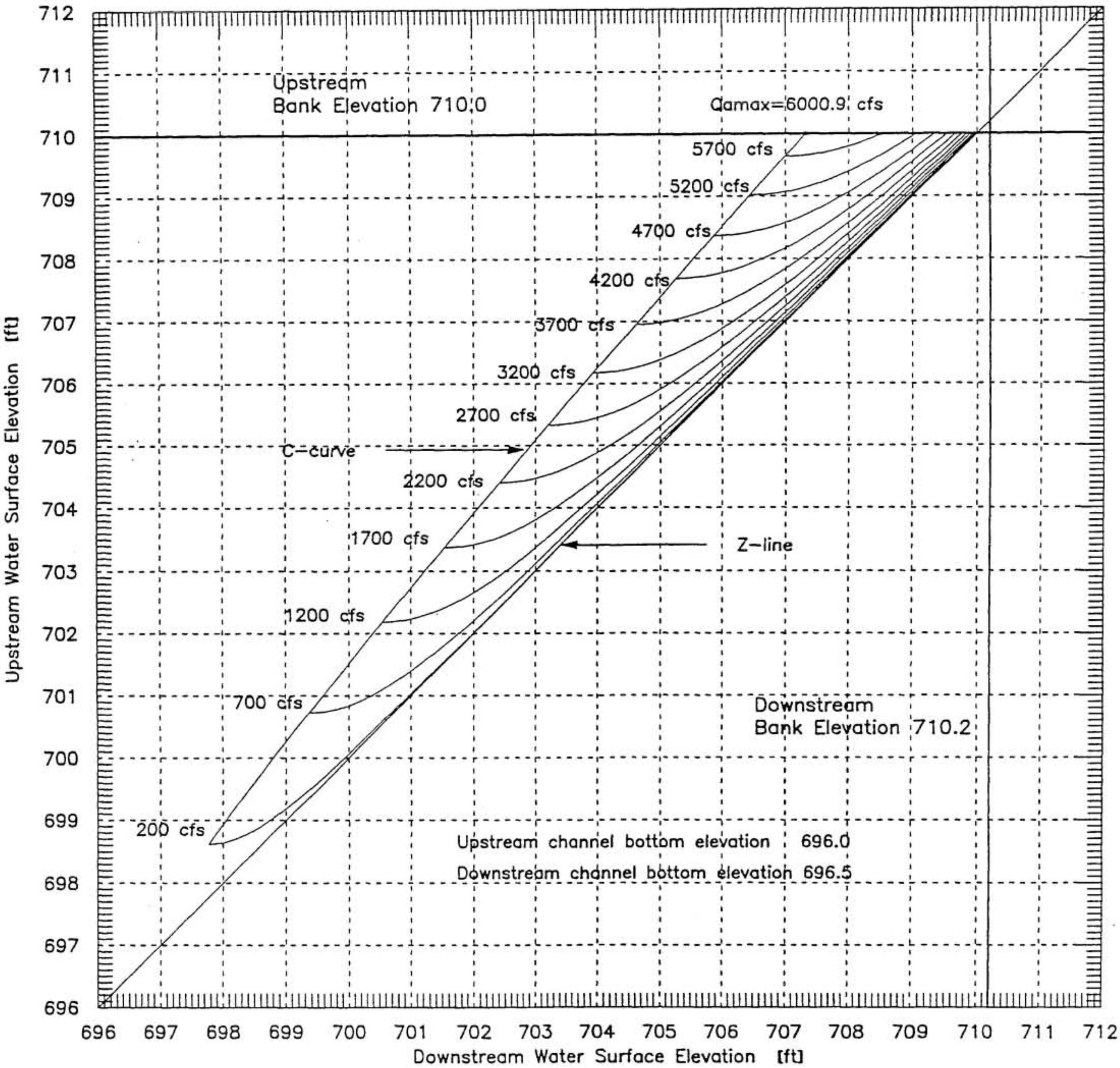

Fig. 3.14 HPG for Reach 14 (U/S Race St. Bridge to D/S of Griggs St. Bridge from Sta 3+360 to Sta 3+840).

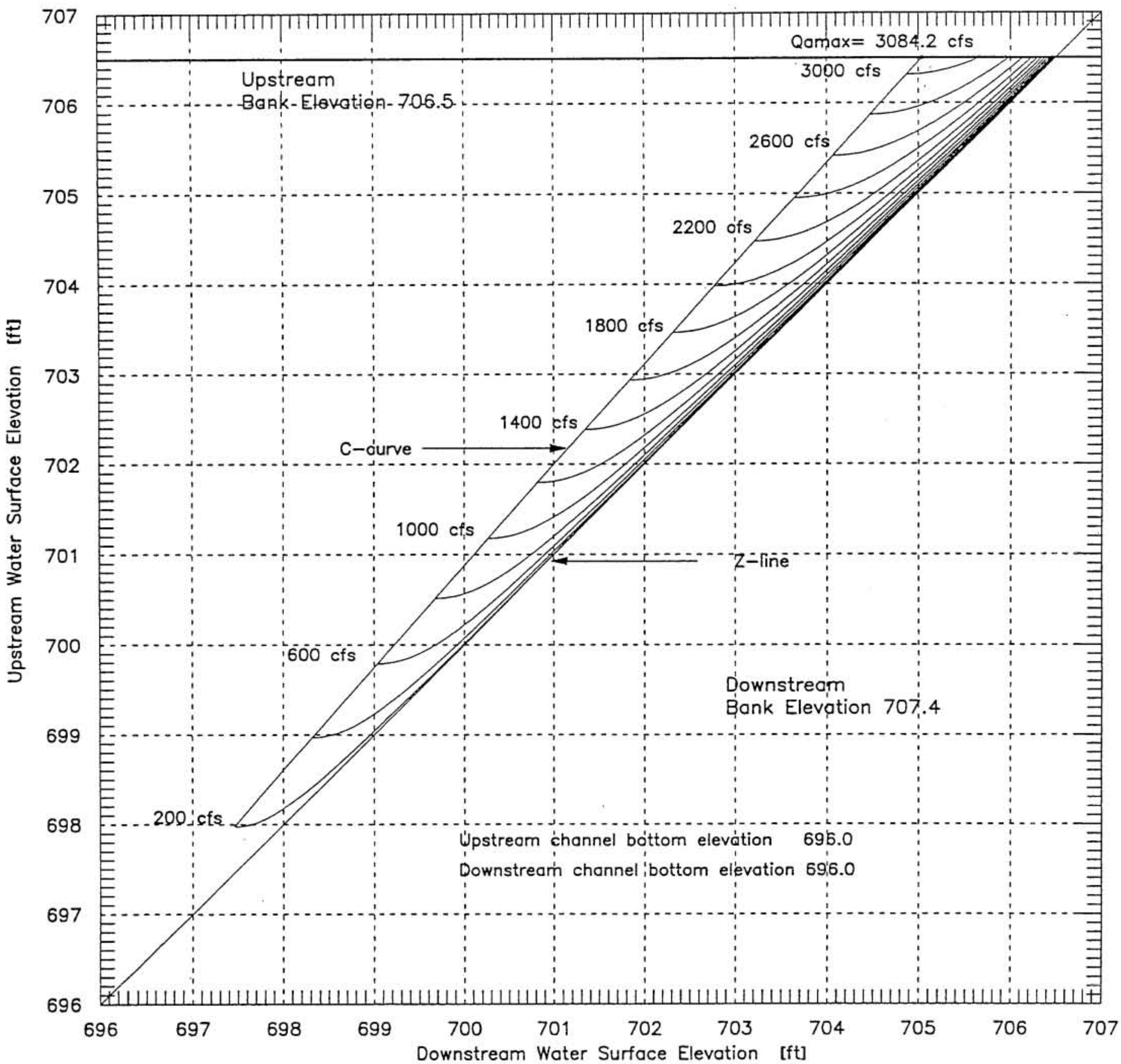

Fig. 3.15*a* HPG for Reach 15 (Griggs St. Bridge from Sta 3+840 to Sta 3+880).

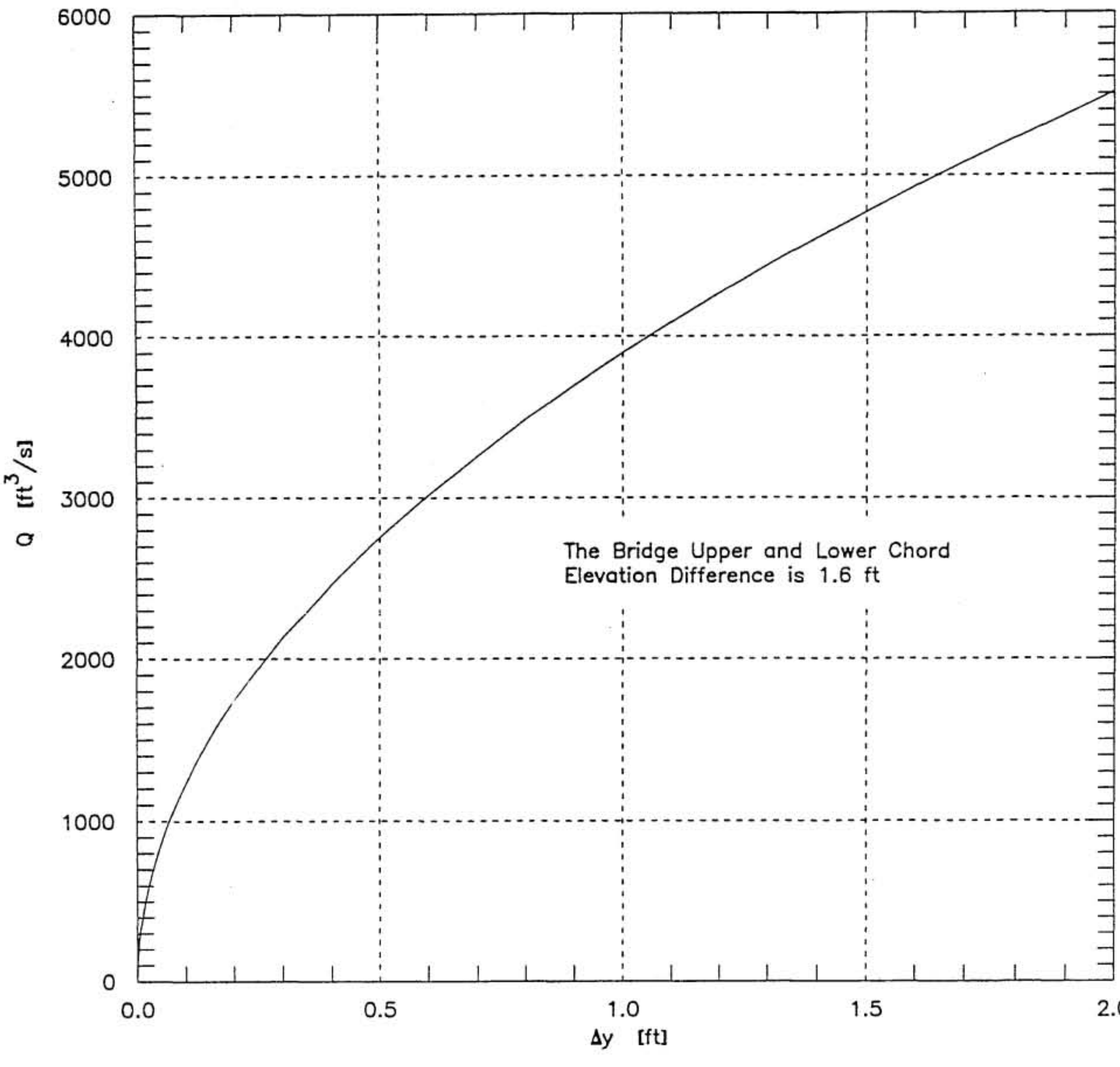

Fig. 3.15*b* Rating Curve for Reach 15 (Griggs St. Bridge from Sta 3+840 to Sta 3+880).

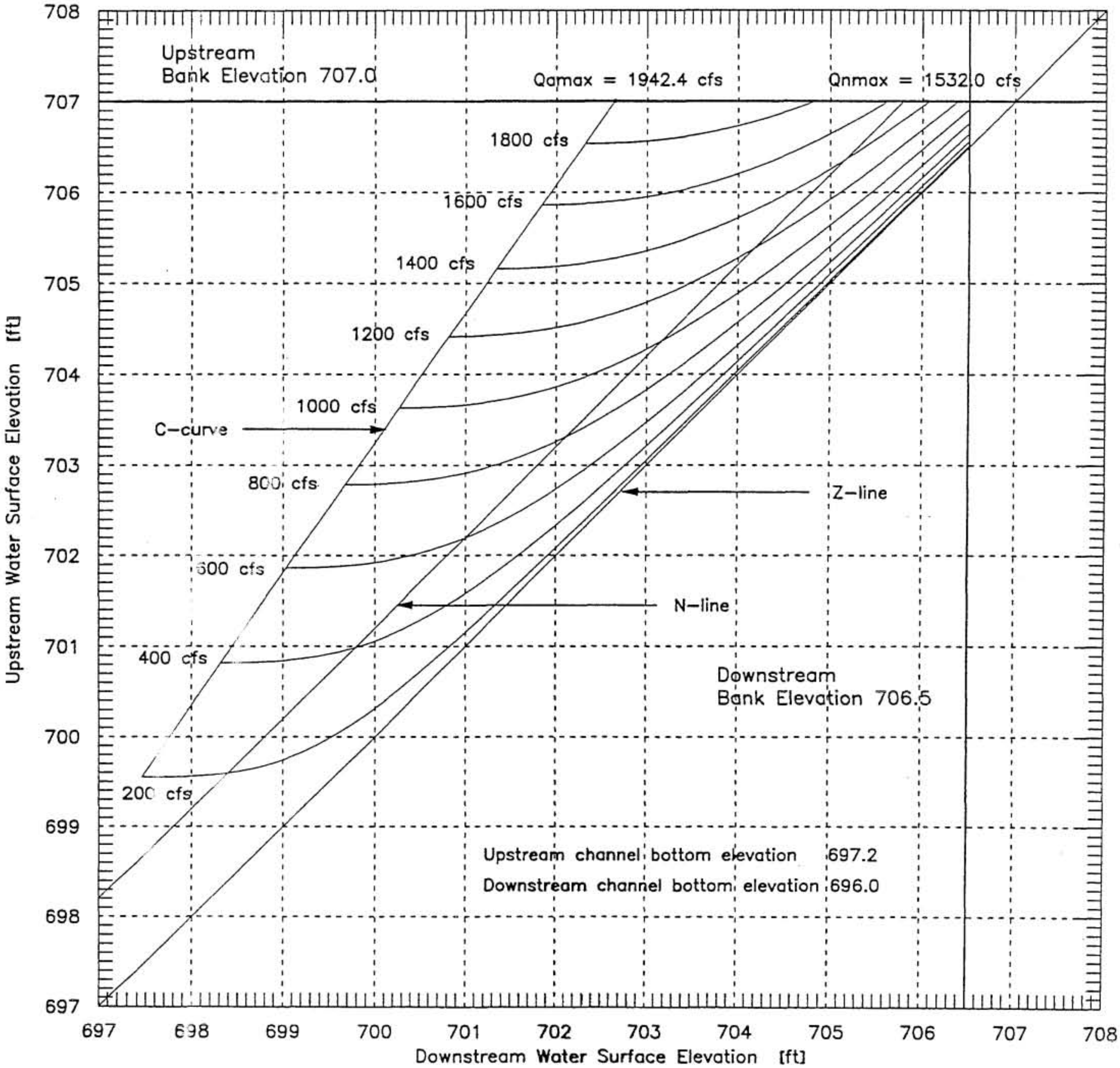

Fig. 3.16 HPG for Reach 16 (U/S of Griggs St. Bridge to D/S of Main St. Bridge, from Sta 3+880 to Sta 4+465).

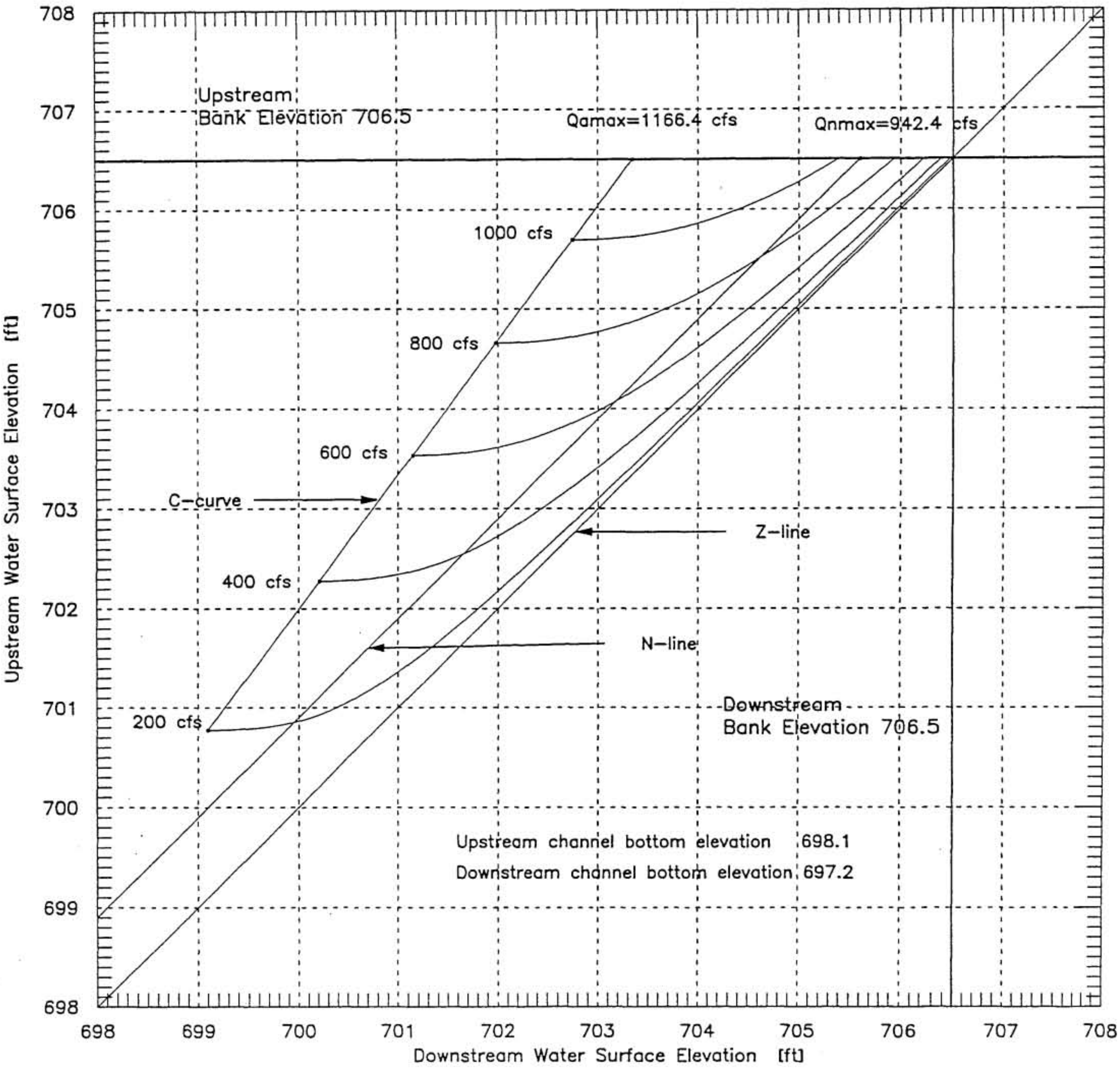

Fig. 3.17*a* HPG for Reach 17 (Main St. Bridge from Sta 4+465 to Sta 4+755).

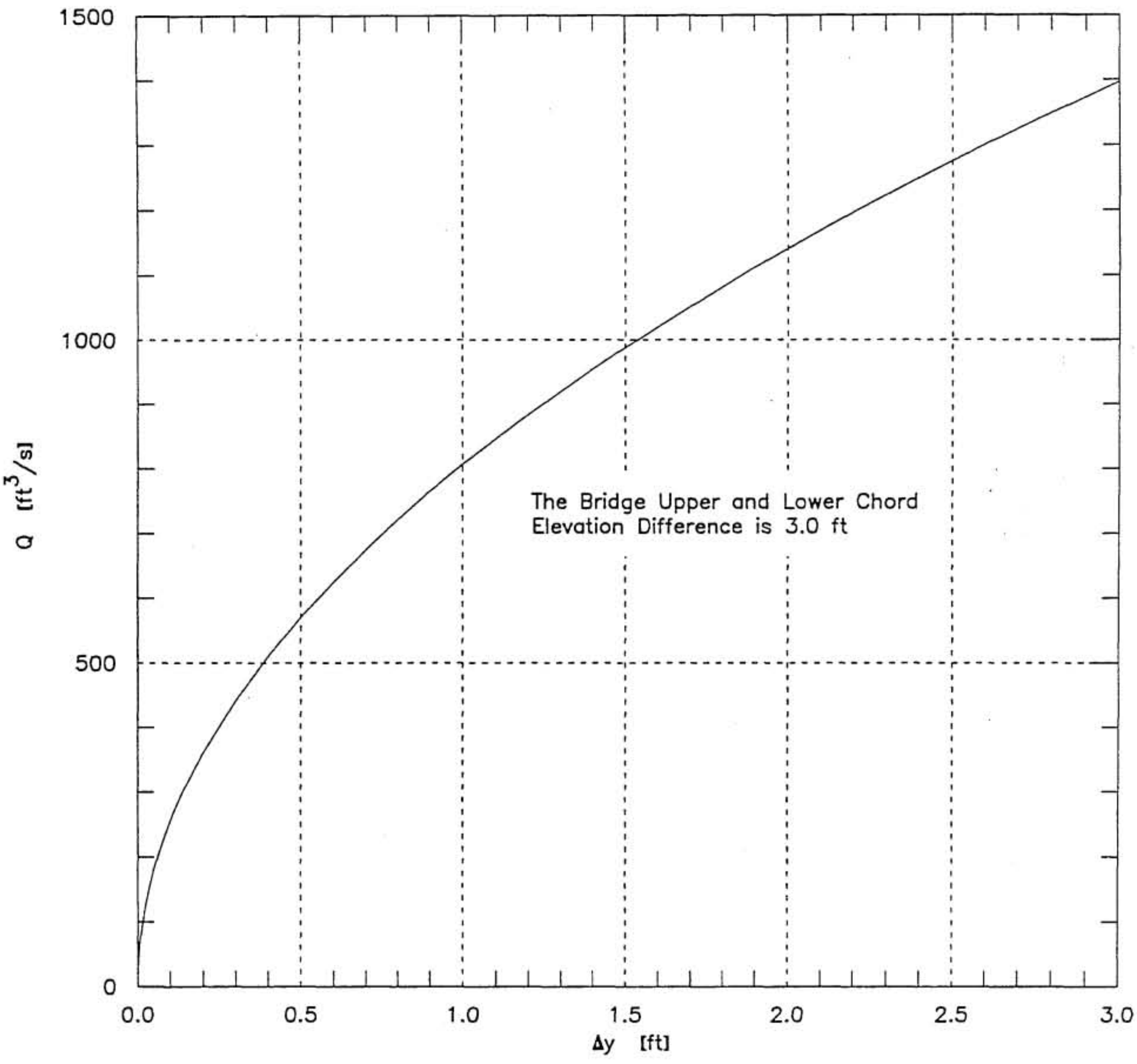

Fig. 3.17*b* Rating Curve for Reach 17 (Main St. Bridge from Sta 4+465 to Sta 4+755).

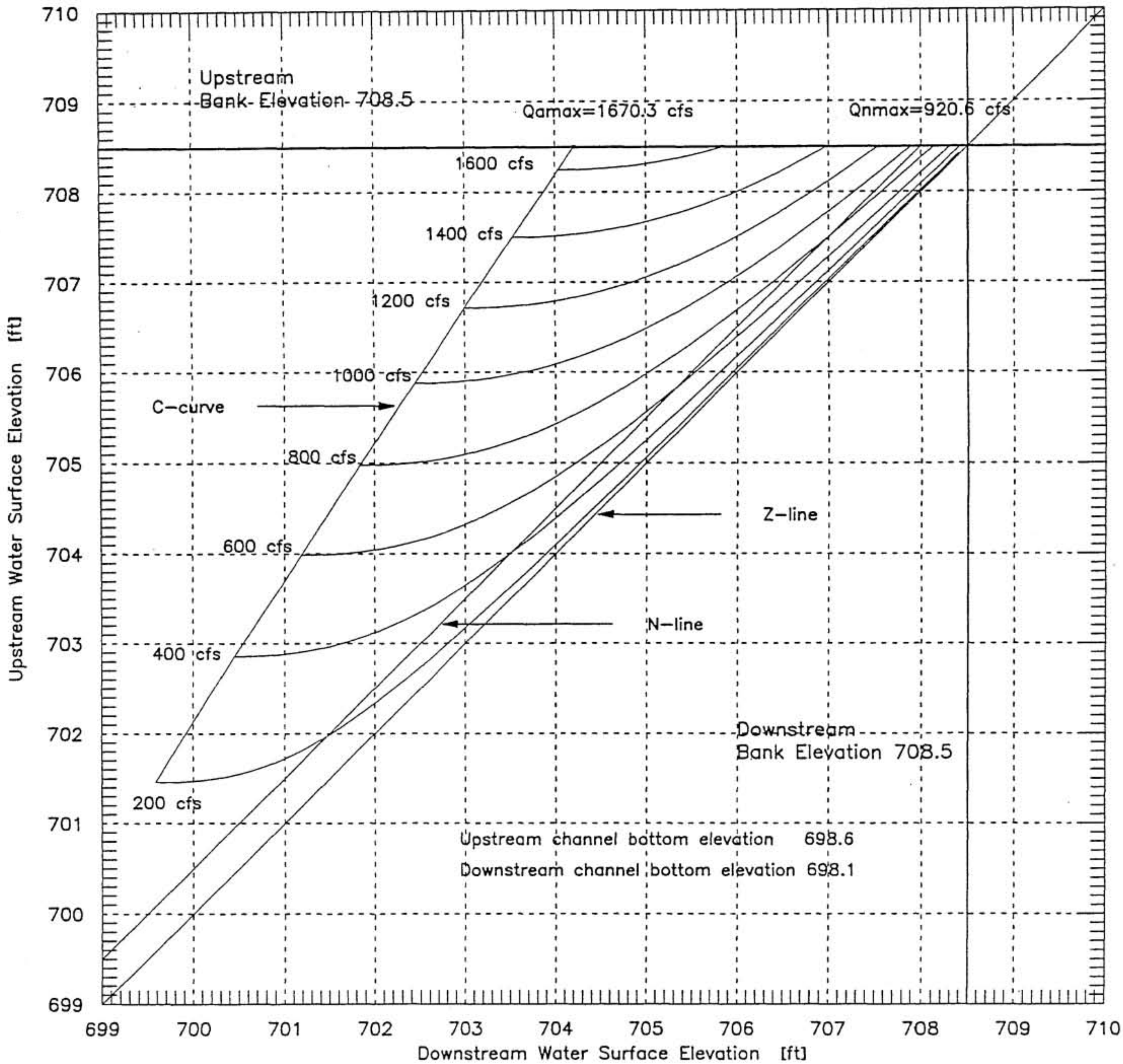

Fig. 3.18 HPG for Reach 18 (U/S of Main St. Bridge to D/S of Mc Cullough St. Bridge from Sta 4+755 to Sta 5+205).

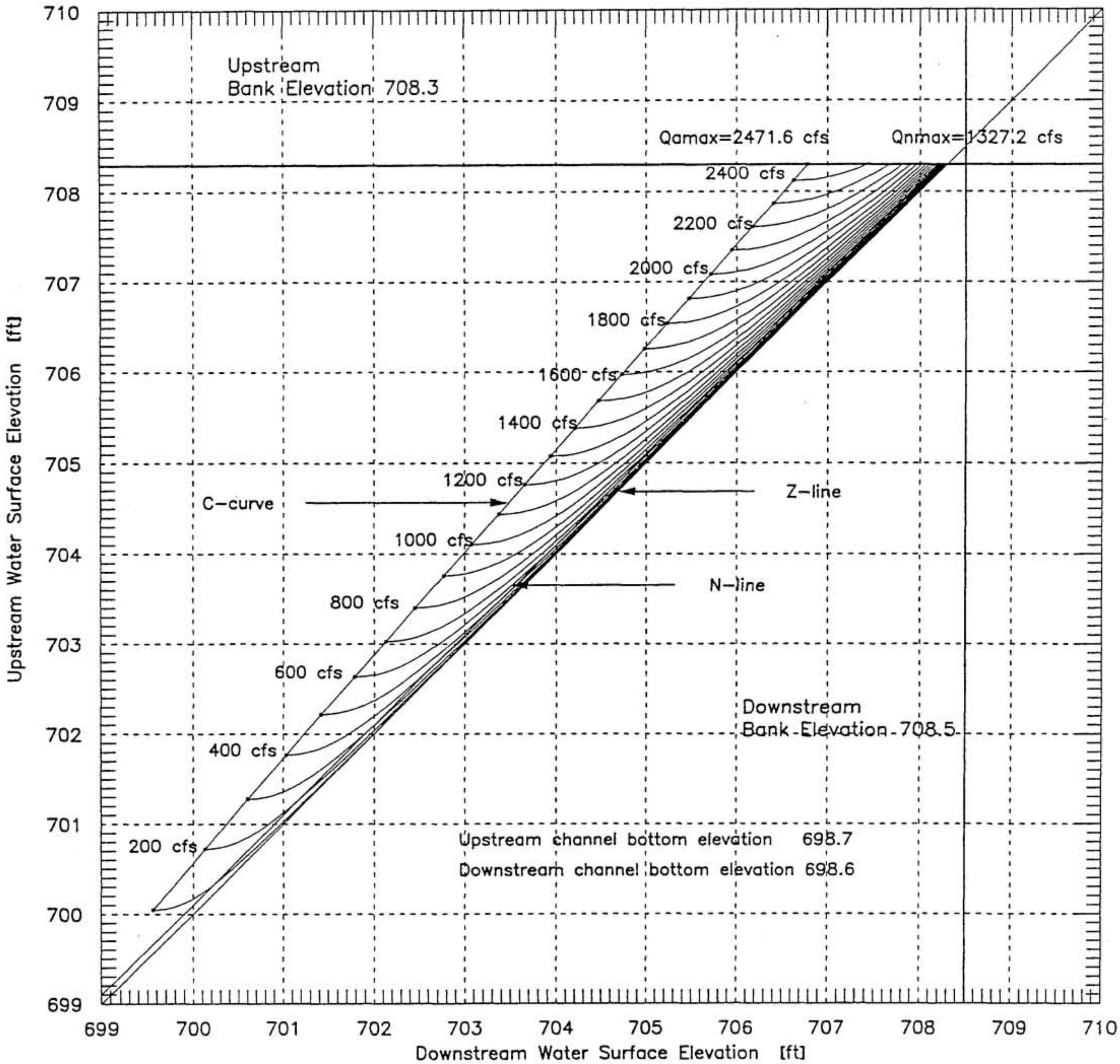

Fig. 3.19*a* HPG for Reach 19a (Mc Cullough St. Bridge from Sta 5+205 to Sta 5+260).

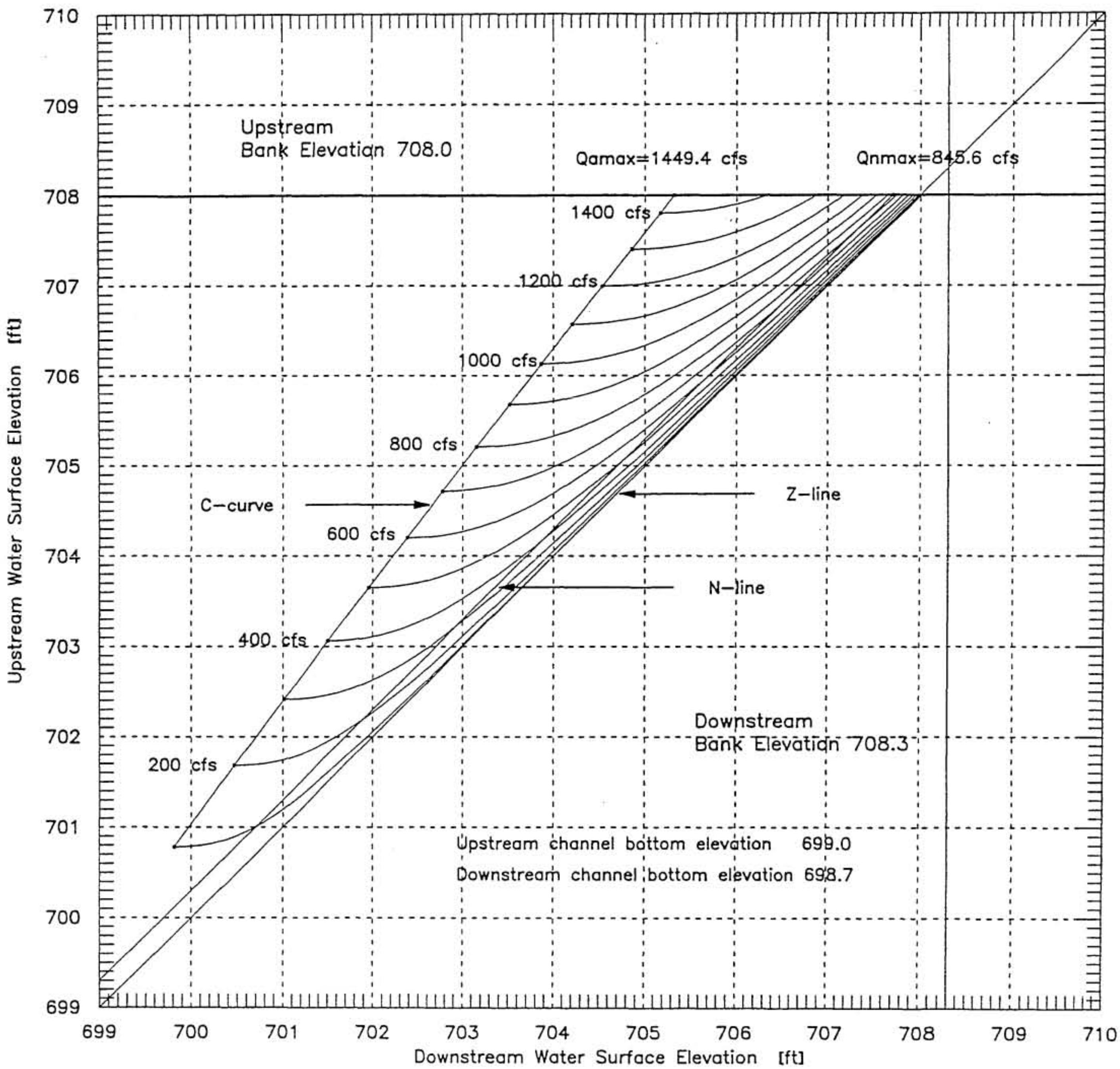

Fig. 3.19*b* HPG for Reach 19b (200-feet Concrete Tunnel by Phillips Recreation Center from Sta 5+260 to Sta 5+460).

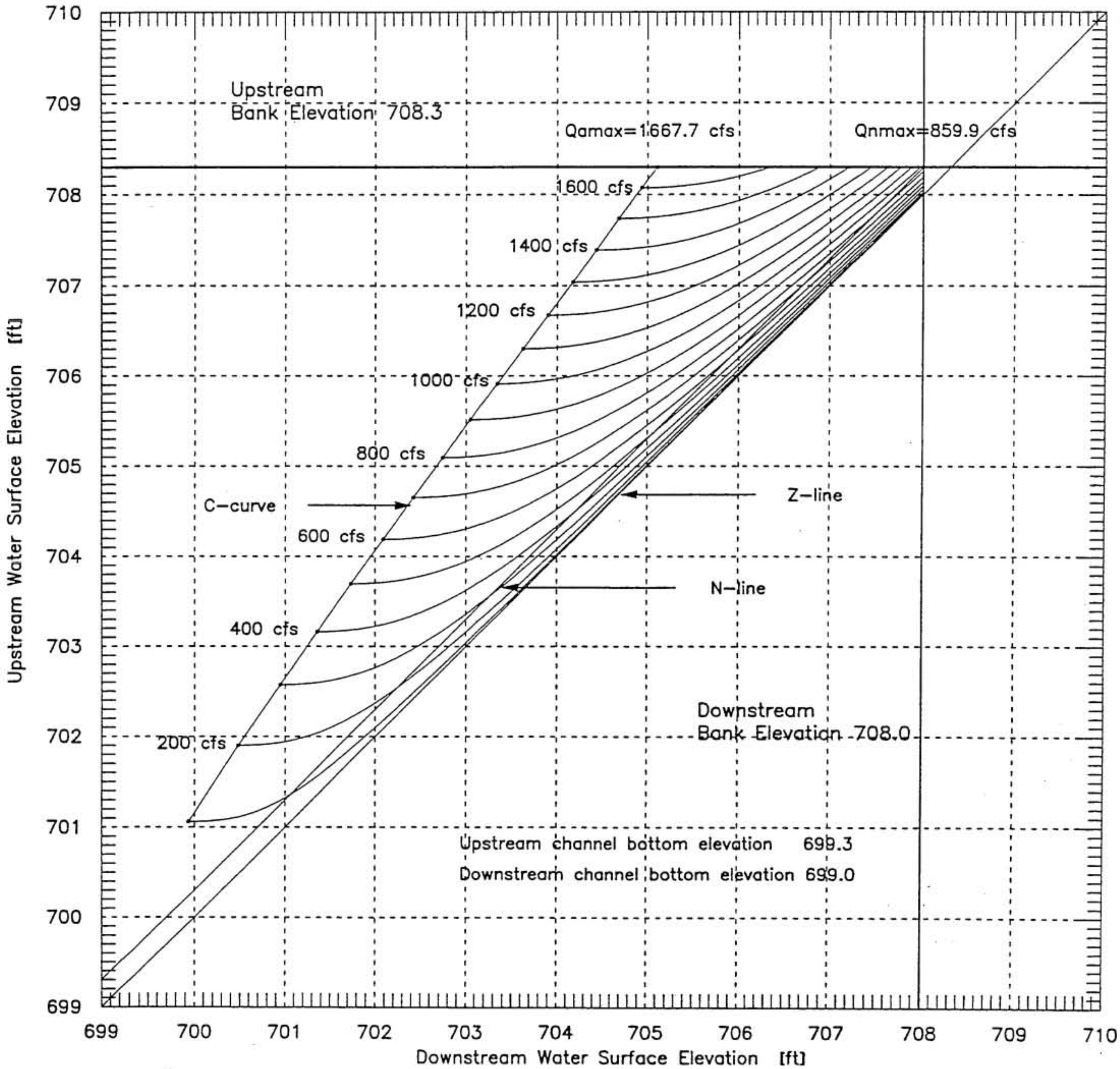

Fig. 3.19*c* HPG for Reach 19c (240-foot Channel Reach Covered with Precast Concrete by Phillips Recreation Center from Sta 5+460 to Sta 5+700).

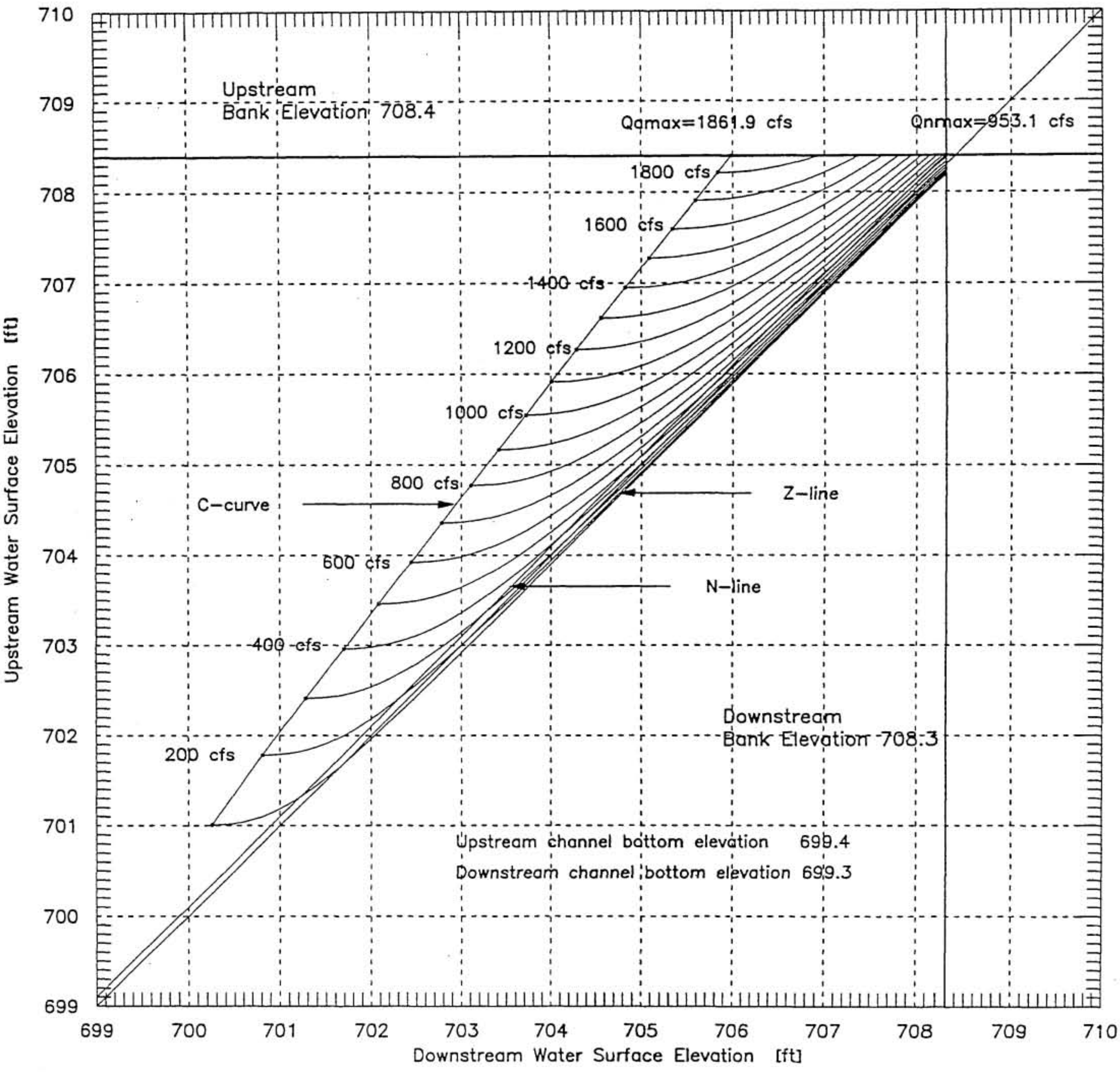

Fig. 3.19*d* HPG for Reach 19d (Springfield Ave. Bridge from Sta 5+700 to Sta 5+795.

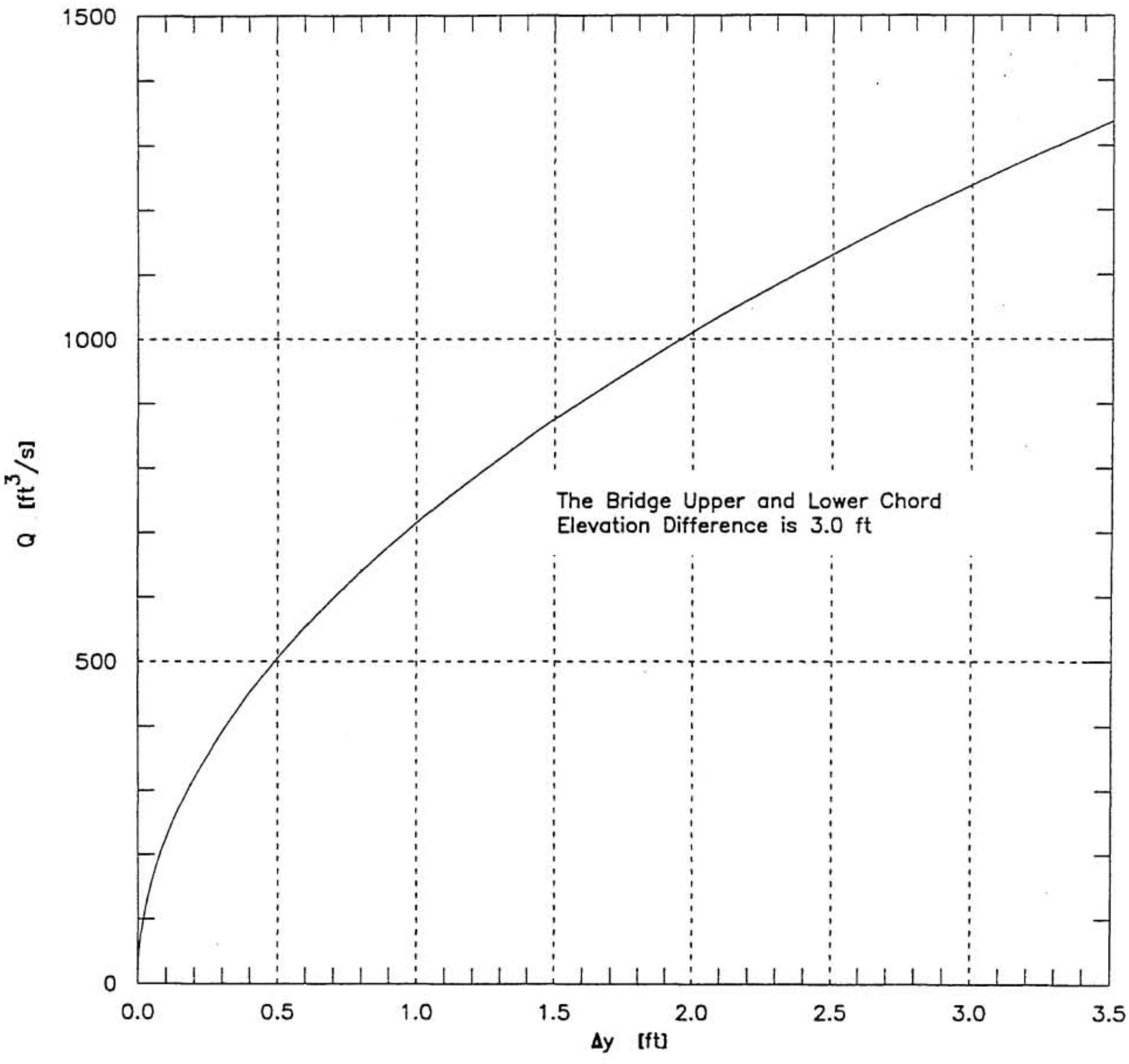

Fig. 3.19*e* Rating Curve for Reaches 19*a* to 19*d* (Closing-Top Reaches by Phillips Recreation – Center between Sta 5+205 and Sta 5+795).

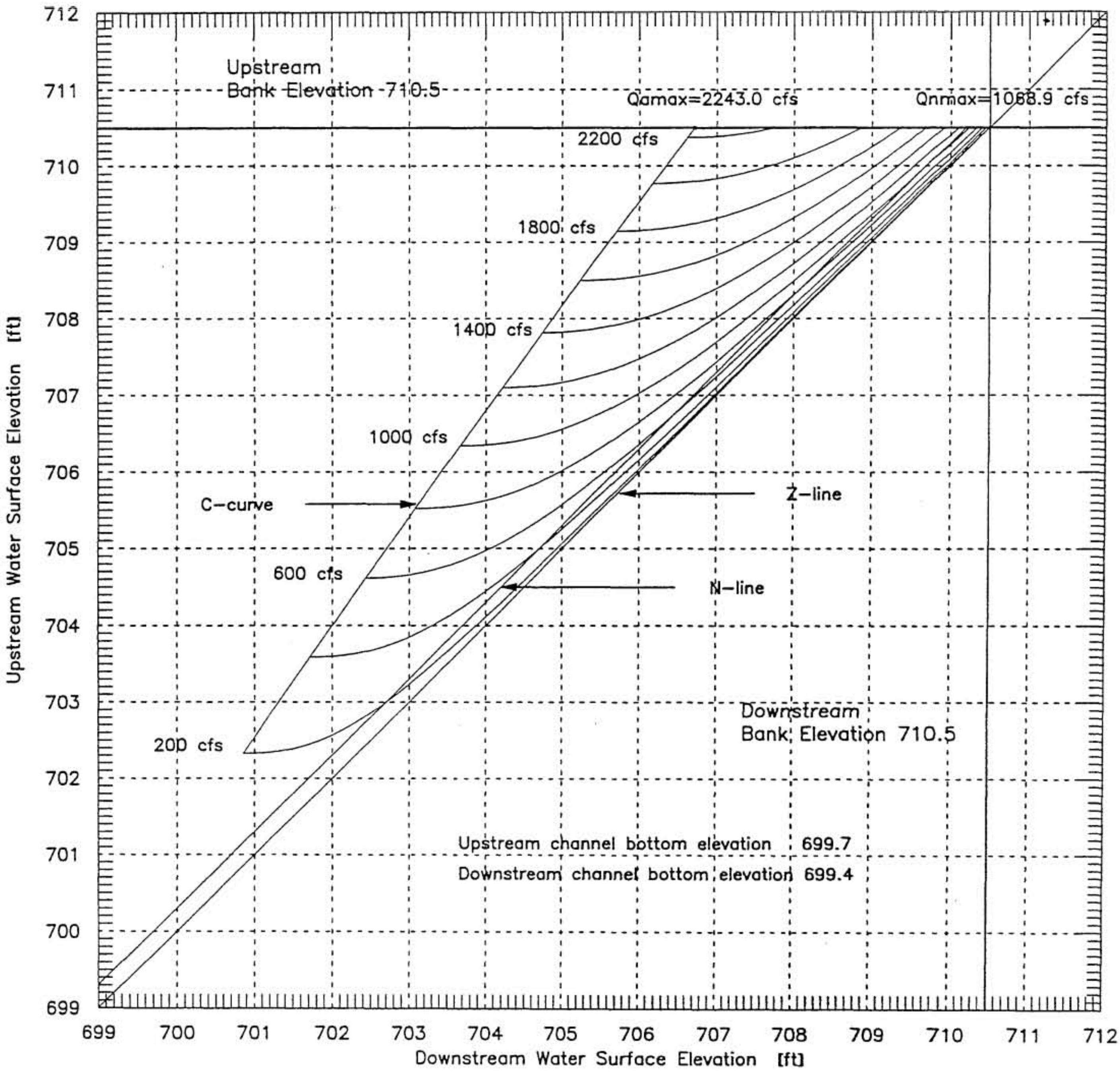

Fig. 3.20 HPG for Reach 20 (U/S of Springfield Ave. Bridge to D/S of Coler St. Bridge from Sta 5+795 to Sta 6+055).

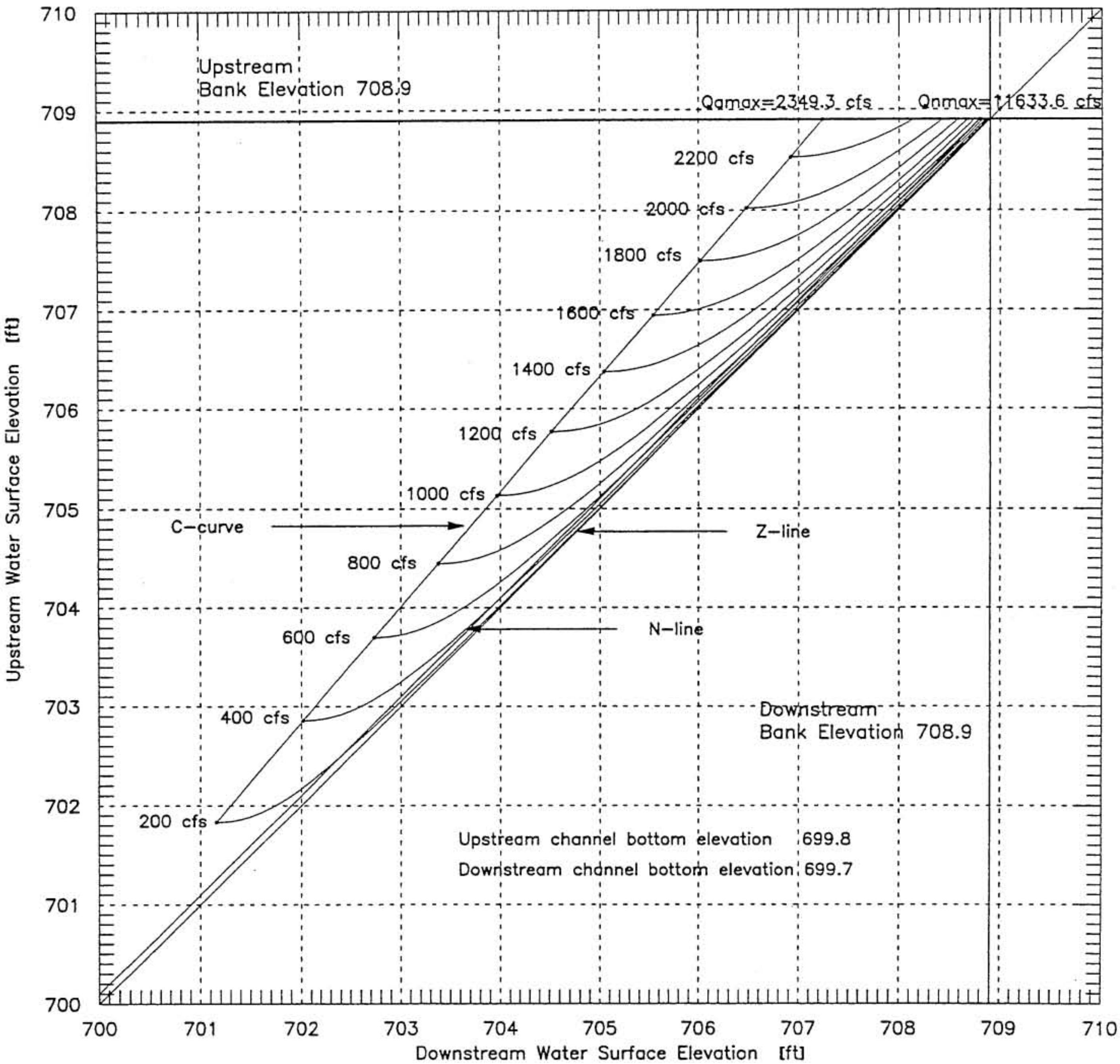

Fig. 3.21*a* HPG for Reach 21 (Coler St. Bridge from Sta 6+065 to Sta 6+140).

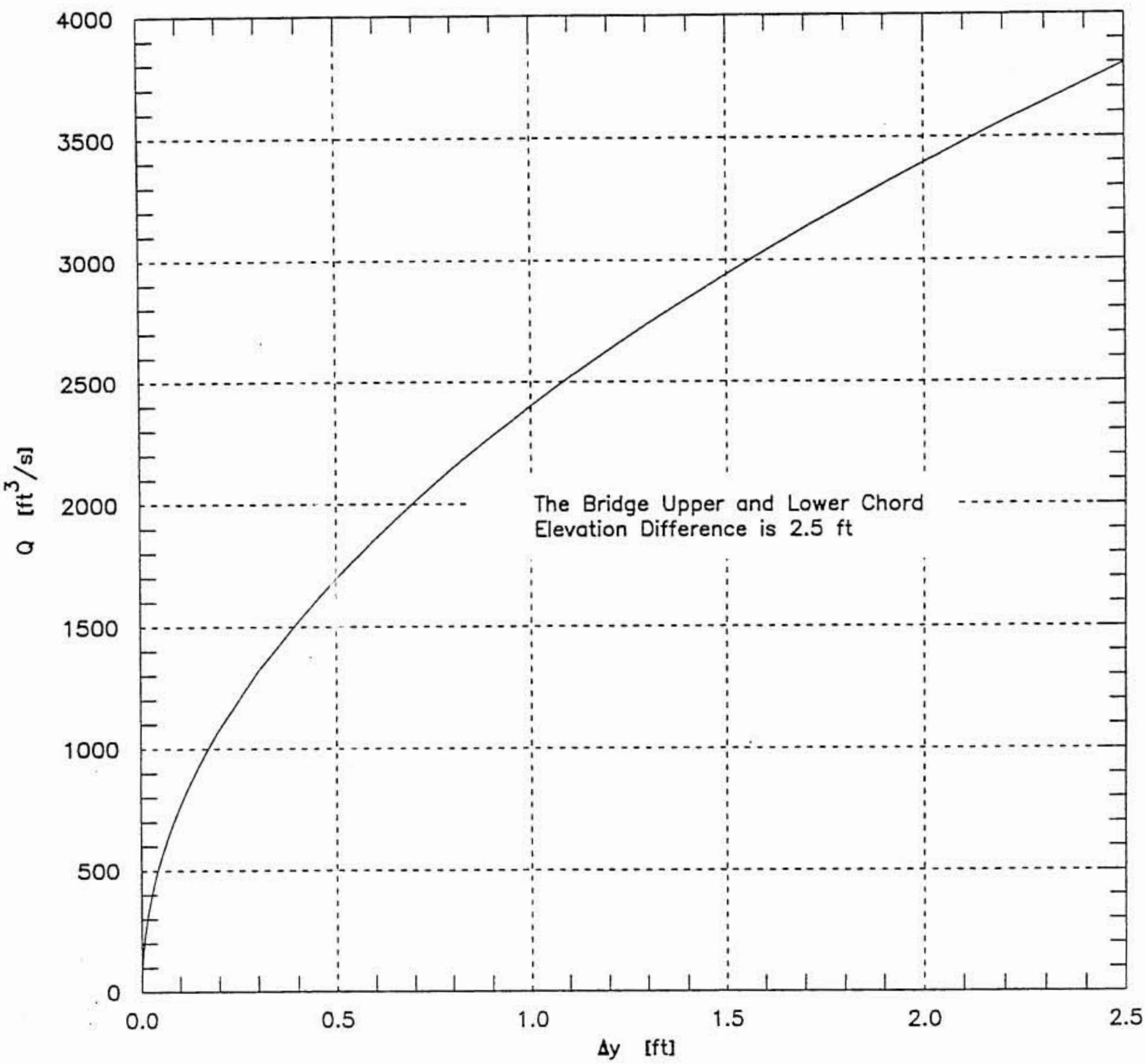

Fig 3.21*b* Rating Curve for Reach 21 (Coler St. Bridge from Sta 6+065 to Sta 6+140).

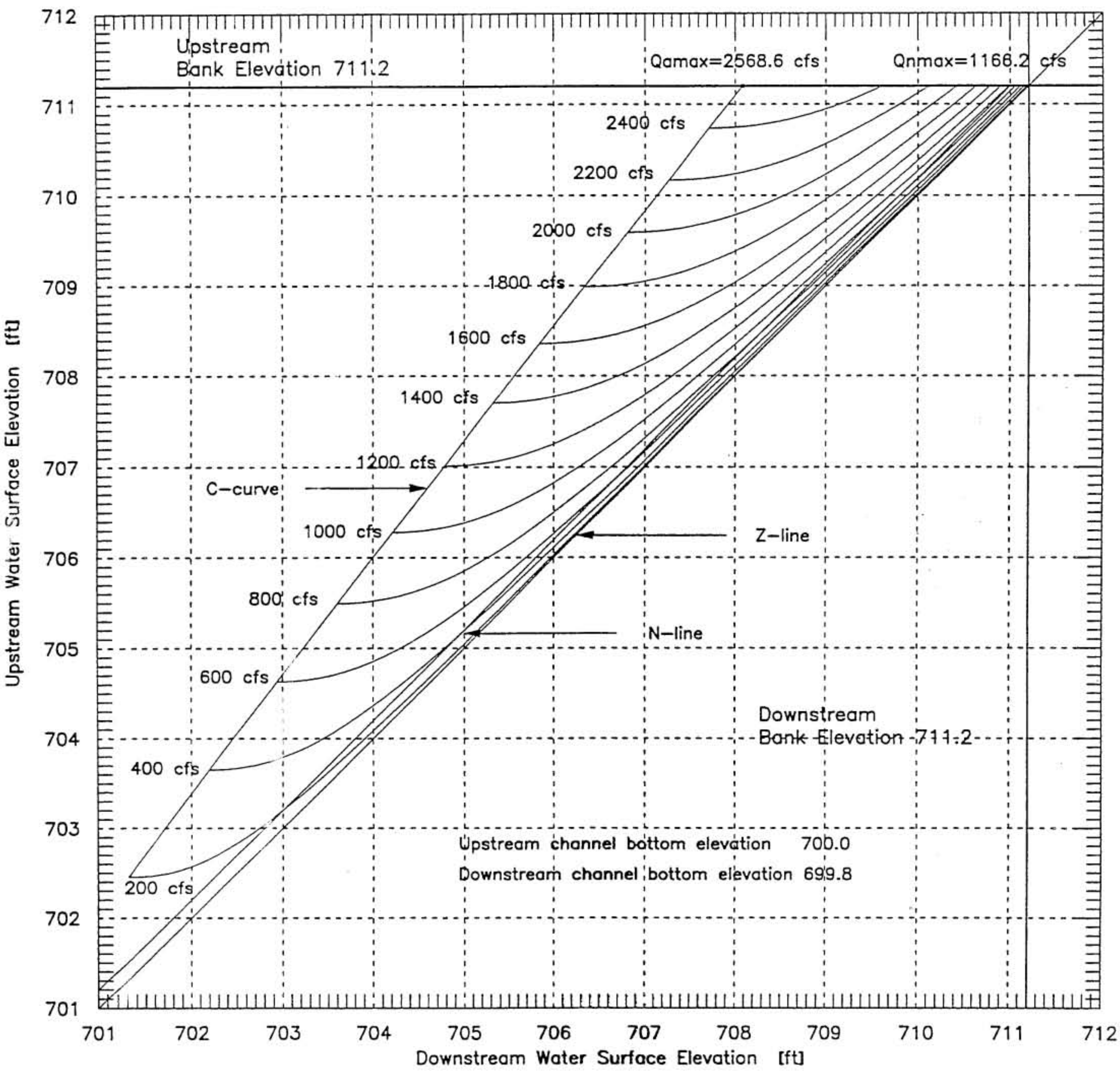

Fig. 3.22 HPG for Reach 22 (D/S of Coler St. Bridge to 12.5 x 7.5 ft Culvert from Sta 6+140 to Sta 6+285).

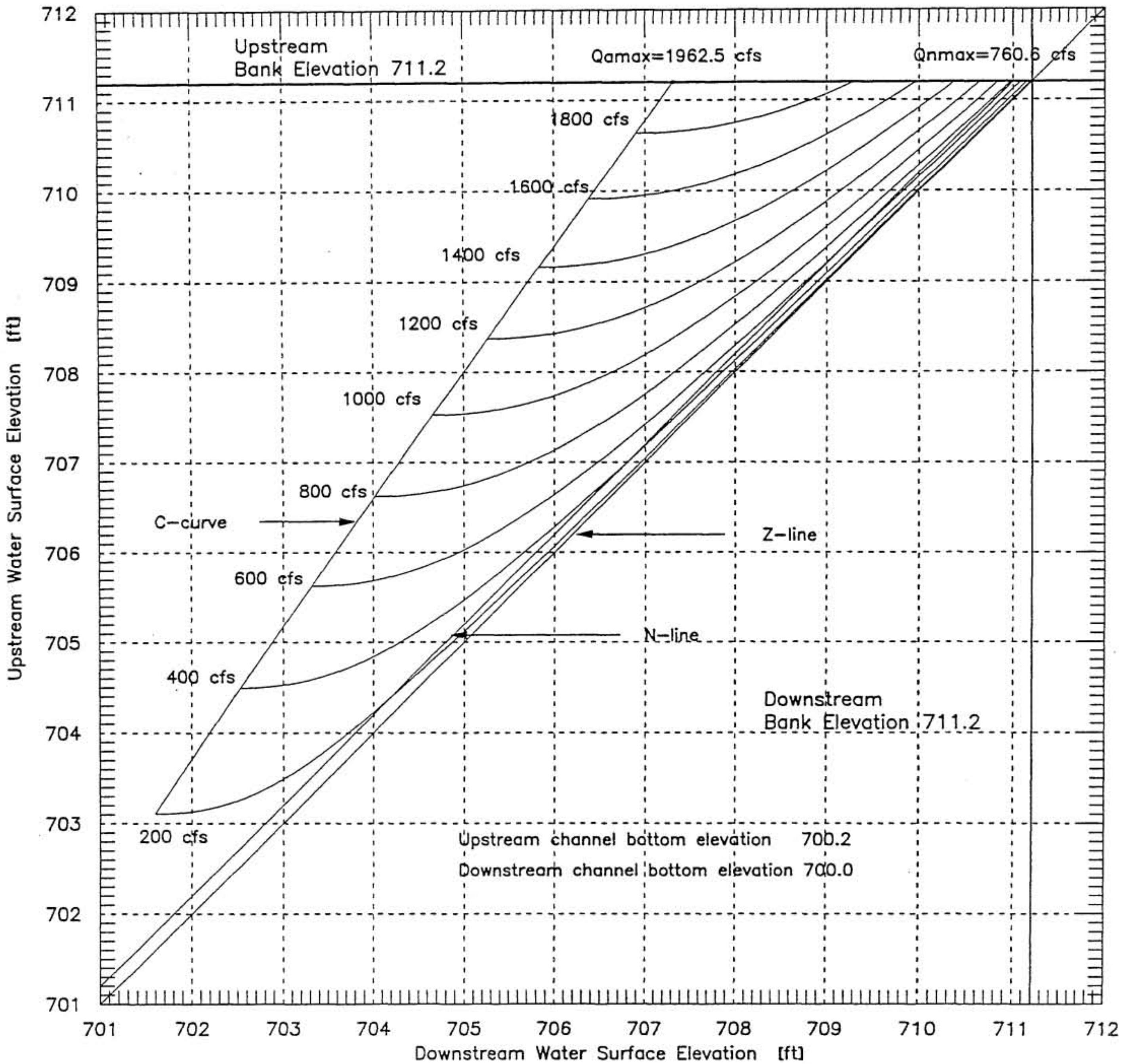

Fig. 3.23 HPG for Reach 23 (U/S of 12.5 x 7.5 ft Culvert to D/S of Busey Ave. Bridge from Sta 6+285 to Sta 6+545).

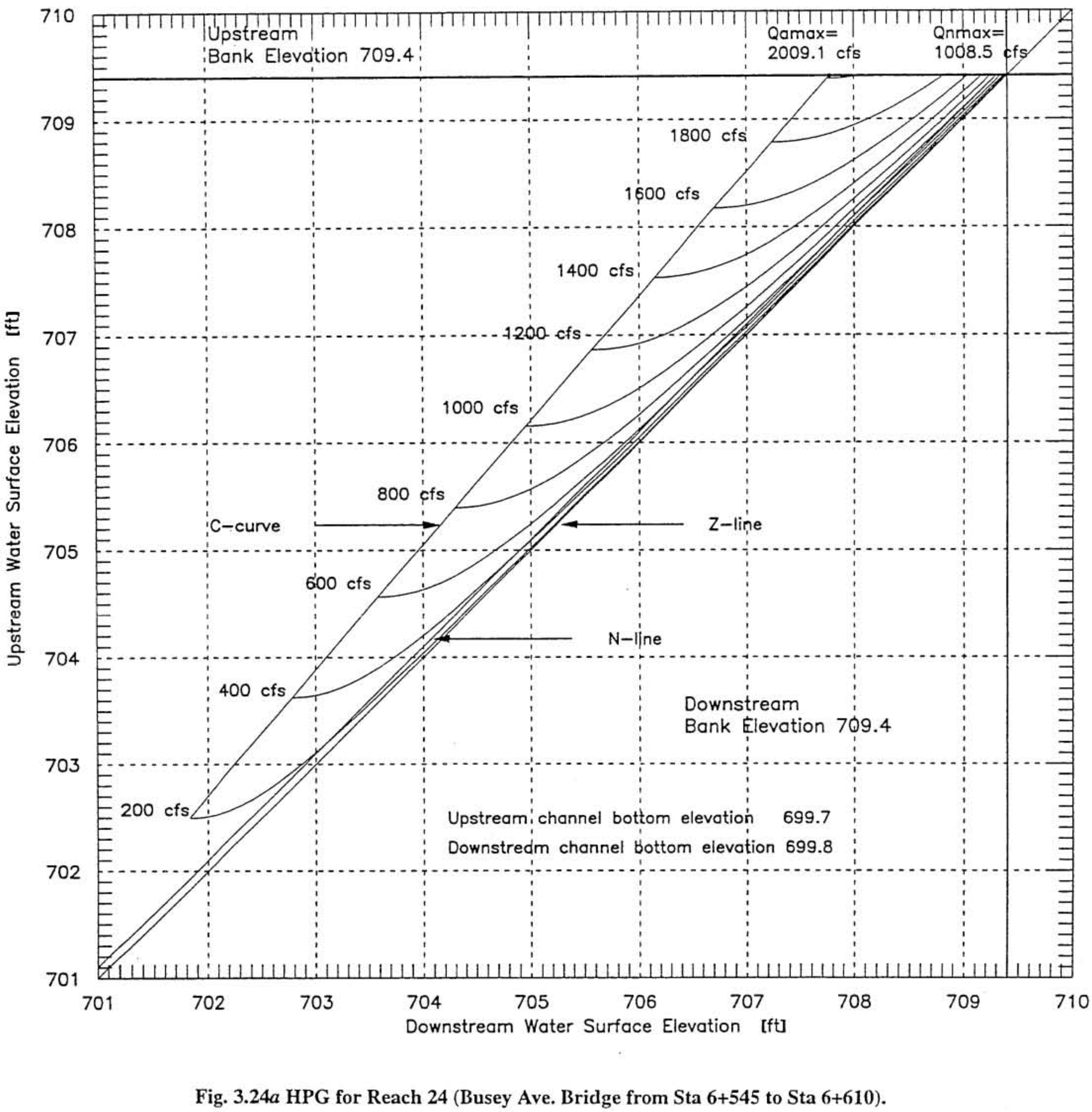

Fig. 3.24*a* HPG for Reach 24 (Busey Ave. Bridge from Sta 6+545 to Sta 6+610).

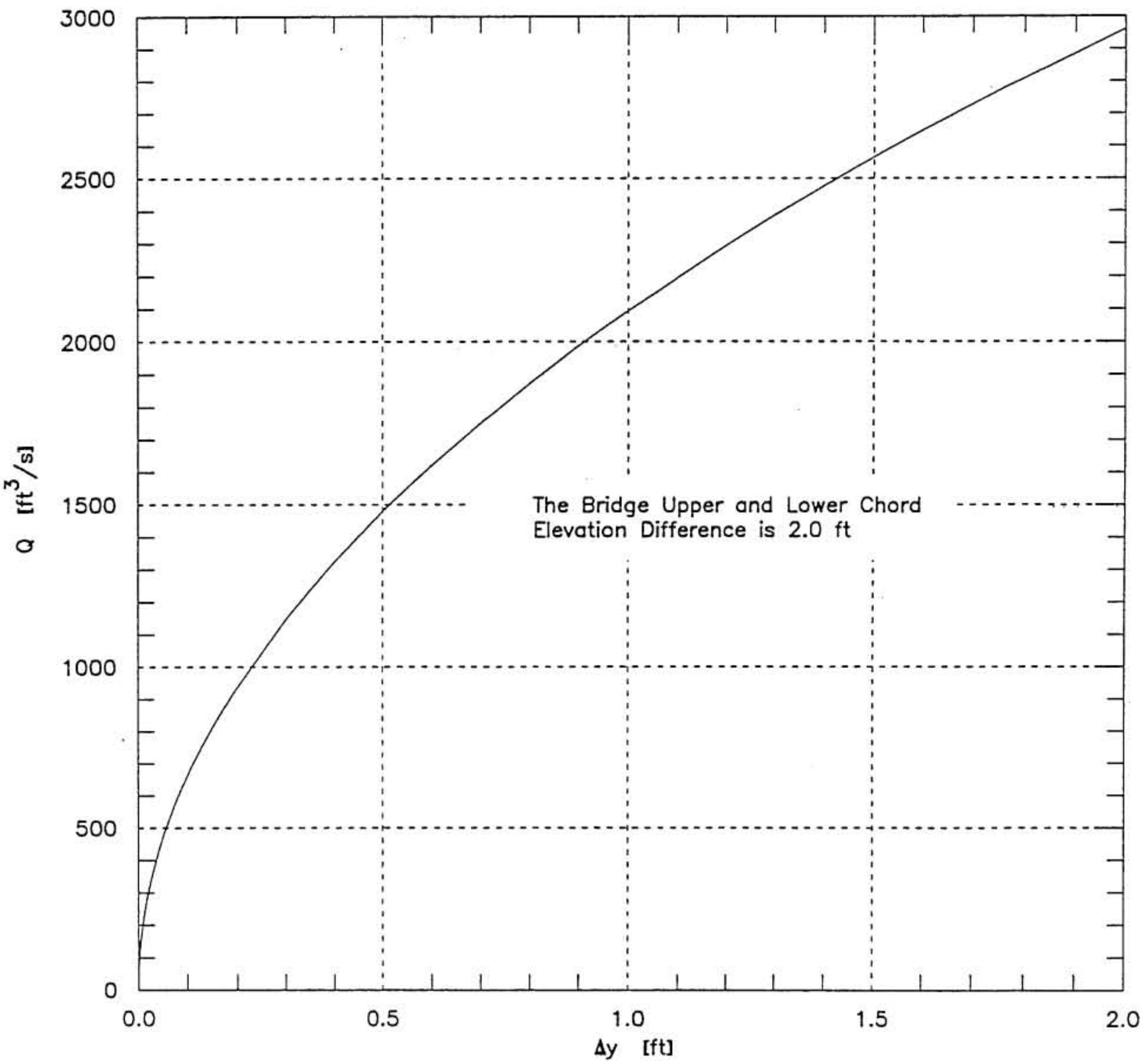

Fig. 3.24*b* Rating Curve for Reach 24 (Busey Ave. Bridge from Sta 6+545 to Sta 6+610).

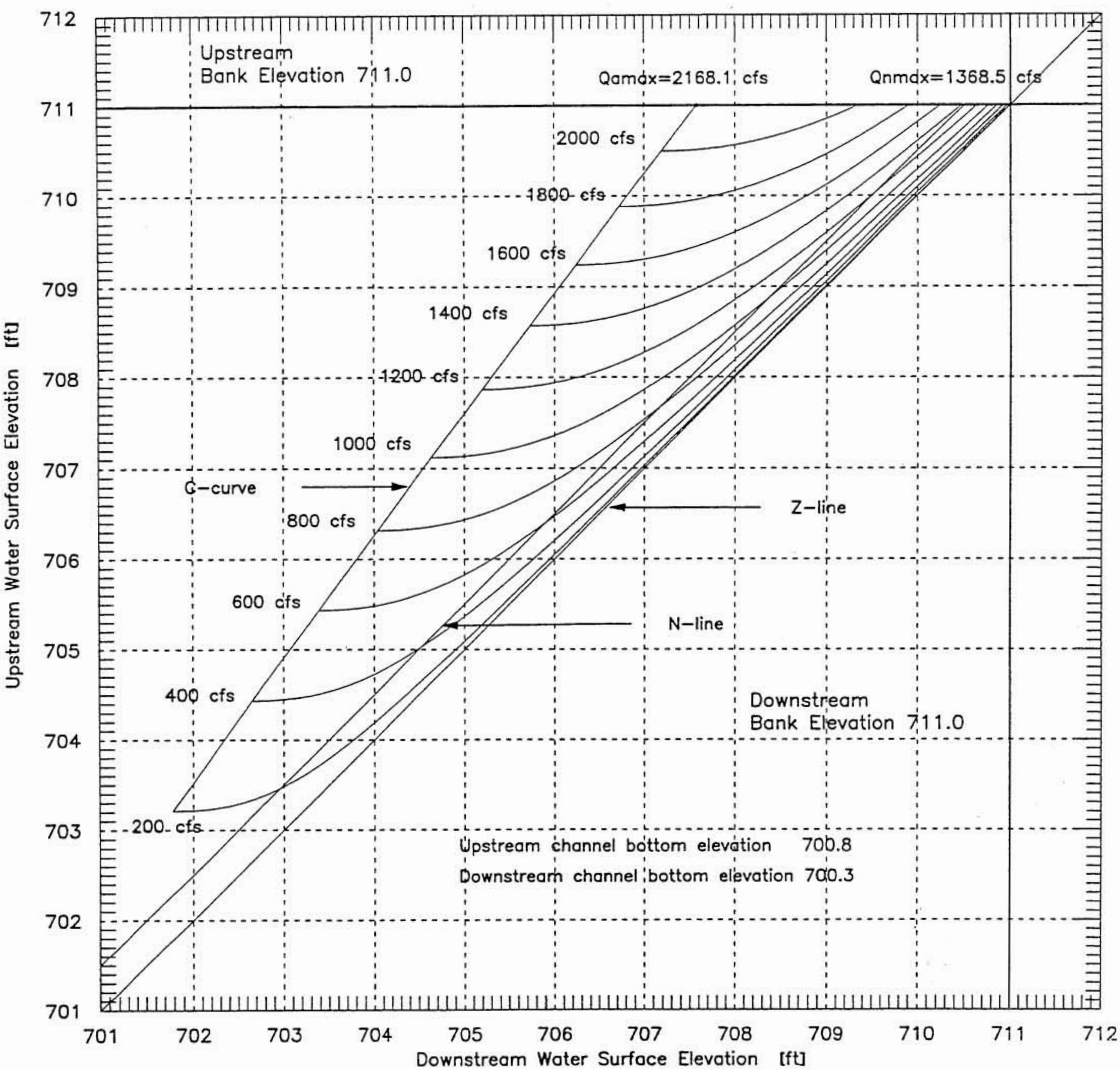

Fig 3.25 HPG for Reach 25 (U/S of Busey Ave. Bridge to D/S of Lincoln Ave. from Sta 6+610 to Sta 6+955).

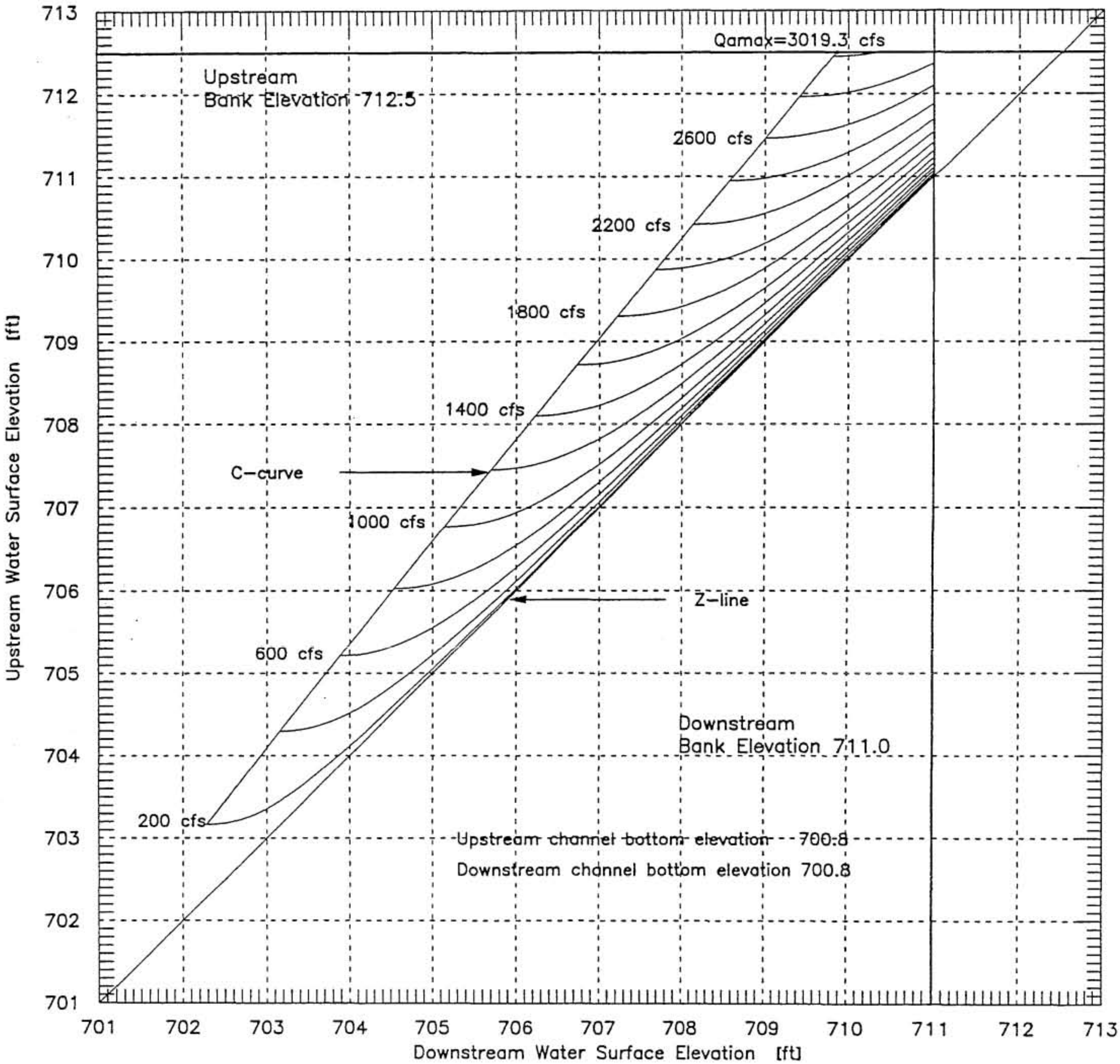

Fig 3.26a HPG for Reach 26 (D/S of Lincoln Ave. to 3-foot Drop Structure at Lincoln Ave. from Sta 6+955 to Sta 7+090).

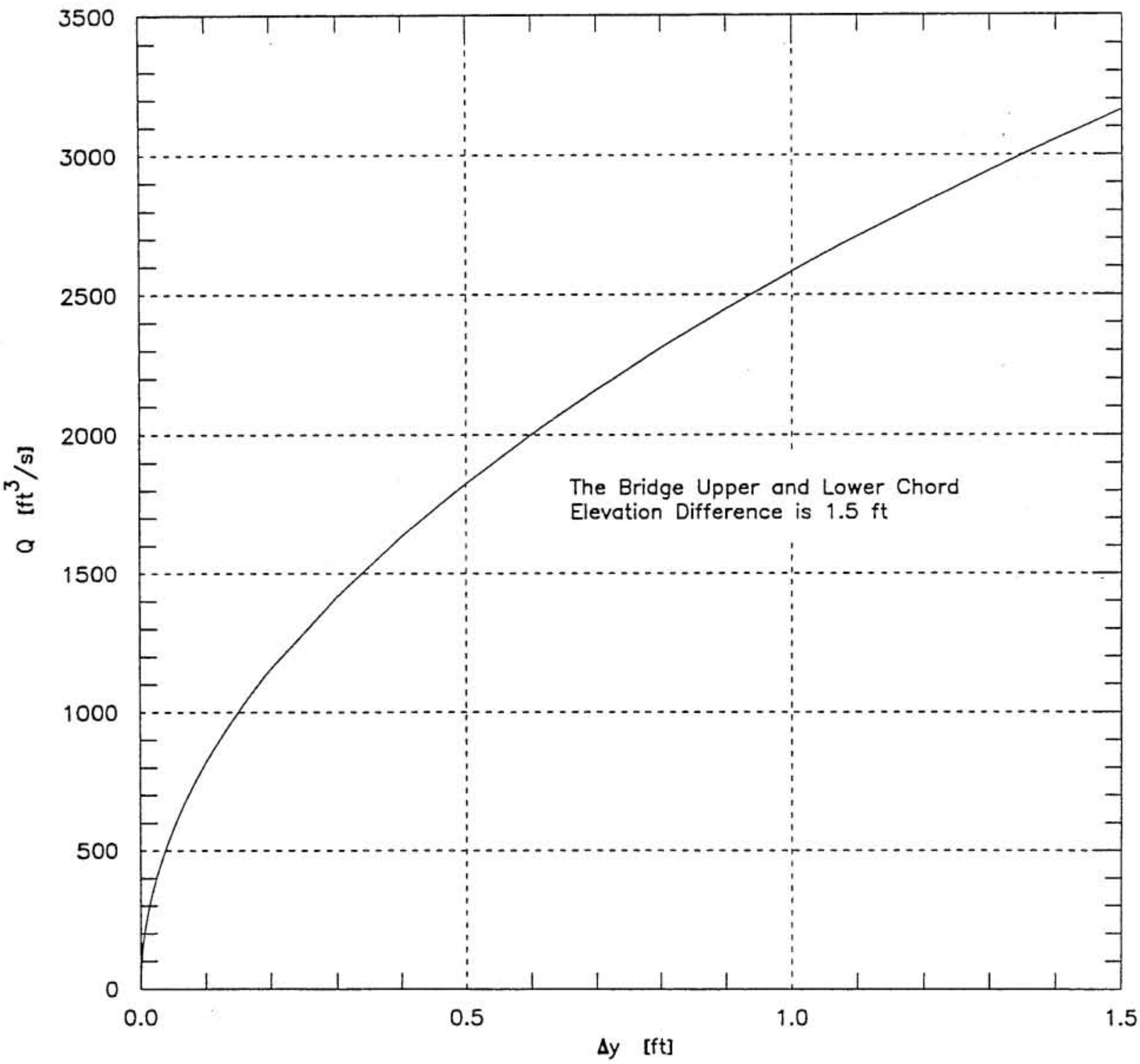

Fig 3.26*b* Rating Curve for Reach 26 (D/S of Lincoln Ave. to 3-foot Drop Structure at Lincoln Ave. from Sta 6+955 to Sta 7+090).

Table 3.1 Maximum Capacities of Individual Reaches of Boneyard Creek between Wright Street and Lincoln Avenue, Condition of May 1995.

Reach	Closing–Top Reaches	Open Channel Reaches	Qamax [1] cfs	Qnmax [2] cfs	Qsmax [3] cfs
1		Saline Branch – Urbana Armory Footbridge	4,067.0	2,489.3	
2		Urbana Armory Footbridge – University Ave. Bridge	3,595.7	3,289.5	
3	University Ave. Bridge		3,168.9	2,093.8	4,090.0
4		University Ave. Bridge – Vine St. Bridge	4,624.1	4,539.4	
5	Vine St. Bridge		2,991.1	horizontal slope	3,045.0
6		Vine St. Bridge – Huey's Bridge	3,757.7	1,610.2	
7	Huey's Bridge		2,218.4	horizontal slope	4,695.0
8		Huey's Bridge – Broadway Ave. Bridge	2,957.8	2,689.4	
9	Broadway Ave. Bridge		3,393.6	2,785.9	4,705.0
10		Broadway Ave. Bridge – PC RR Bridge	3,738.4	1,137.0	
11	PC RR Bridge		6,162.3	3,759.9	7,650.0
12		PC RR Bridge – Race St. Bridge	6,597.7	4,009.5	
13	Race St. Bridge		5,615.6	8,509.0	10,710.0
14		Race St. Bridge – Griggs St. Bridge	6,000.9	adverse slope	
15	Griggs St. Bridge		3,084.2	horizontal slope	4,920.0
16		Griggs St. Bridge – Main St. Bridge	1,942.4	1,532.0	
17	Main St. Birdge		1,166.4	942.4	1,397.0
18		Main St. Bridge – Mc Cullough St. Bridge	1,670.3	920.6	
19a	Mc Cullough St. Bridge		2,471.6	1,327.2	1,245.0
19b	200–foot Concrete Tunnel		1,449.4	845.7	1,245.0
19c	240–foot Reach Covered with Precast Concrete		1,667.7	859.9	1,245.0
19d	Springfield Ave. Bridge		1,861.9	953.1	1,245.0
20		Springfield Ave. Bridge–Coler St. Bridge	2,243.0	1,068.9	
21	Coler Ave. Bridge		2,349.3	1,163.6	3,800.0
22		Coler Ave. Bridge–12.5x7.5 ft Culvert	2,568.6	1,166.2	
23		12.5x7.5 ft Culvert–Busey Ave. Bridge	1,962.5	760.6	
24	Busey Ave. Bridge		2,009.1	1,008.5	2,960.0
25		Busey Ave. Bridge–Lincoln Ave. Bridge	2,168.1	1,368.5	
26	3–foot Drop Structure		3,019.3	horizontal slope	

[1] Absolute maximum capacity. [2] Maximum uniform flow capacity. [3] Maximum surcharged capacity.

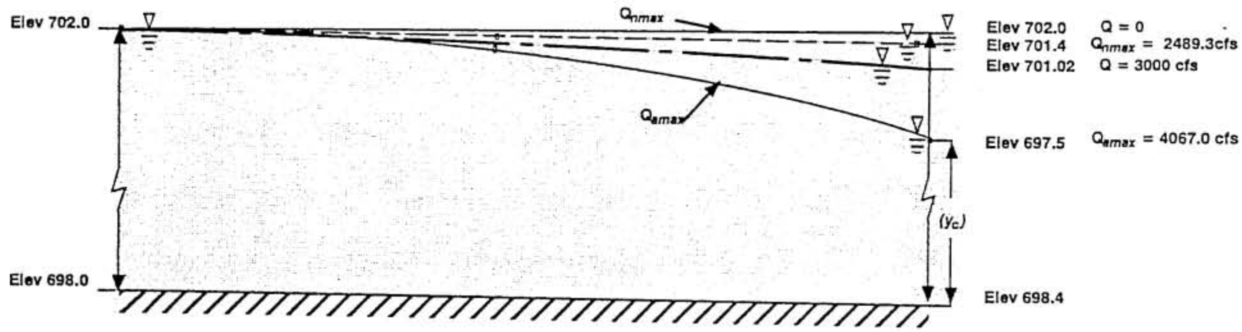

Fig. 3.27 Water Surface Profiles for Different Threshold Hydraulic Capacities in Open-Channel Reach 1.

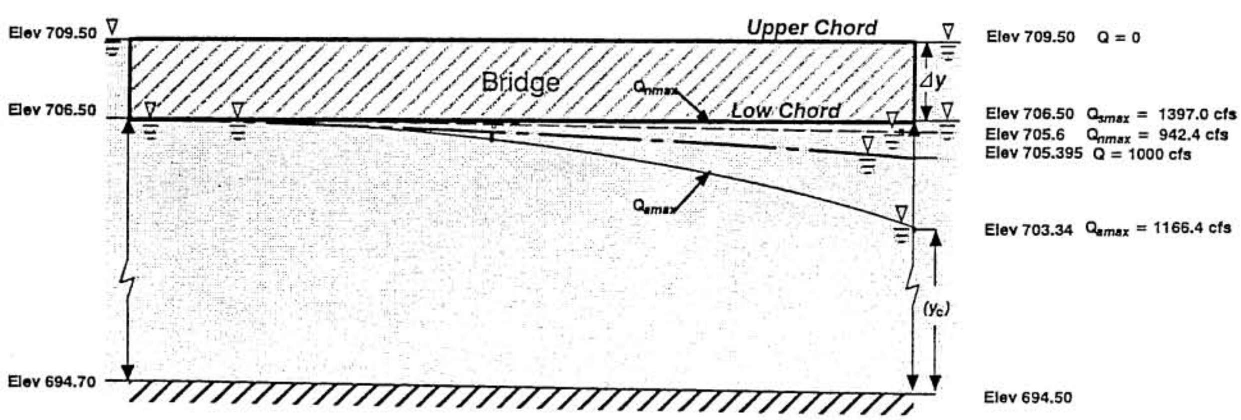

Fig. 3.28 Water Surface Profiles for Different Hydraulic Capacities in Closing-Top Reach 17.

4. CAPACITY DETERMINATION AND BOTTLENECK IDENTIFICATION

The capacities of each channel reach presented in the preceding chapter are only limiting values of the capacity when each individual element of the channel system is acting independently of other reaches. The overall capacity of the channel system, however, is different from any of the capacity values of the individual reaches due to the interaction between reaches. For a channel system the backwater effect of connecting reaches usually prevents the exit depth of interior reaches from becoming critical. Therefore, the absolute maximum capacity of a reach, ***Qamax***, serves as the upper bound provided open-channel flow prevails in the reach and also in adjacent reaches. For a closing-top reach the upper bound is the larger of ***Qamax*** and ***Qsmax***. For an open-channel reach connected to a closing-top reach at either its upstream or downstream end, or both, the upper bound is the smaller between ***Qamax*** and the largest discharge allowed under submerged exit or entrance condition of the open-channel reach. The capacity of the system as a whole cannot exceed the smallest of the upper bound of the individual reaches just mentioned, adjusted for lateral flow entering the interior reaches in the channel. In general, however, the location of the bottleneck that determines the capacity of the channel as a system is not in the reach with the smallest upper bound capacity, and thus the system capacity is usually smaller than the smallest upper bound.

4.1 Hydraulic Capacity and Bottleneck Identification for Current Conditions

The overall capacity of a channel system can be determined using the set of the ***HPG***'s and rating curves of the individual system's reaches in sequence. The overall capacity of channel system is defined as the discharge exiting the last reach of the system when spilling overbank is about to occur at least at one spot anywhere in the system. It is apparent that the overall capacity of a channel system is a function of the water surface elevation at the exit station. As the water stage at the exit of the system increases the channel capacity decreases, and the system's maximum capacity is reached when the flow is critical at its exit station. For a given capacity of the system, the corresponding discharge flowing through a reach inside the system is smaller than the discharge at the system's exit if lateral flow is entering the system between this reach and the exit station.

The *HPG* method for capacity determination proposed by Yen and González (1994) was used in this study to determine the overall capacity of the Boneyard Creek in Urbana Illinois. Lateral flow contributions to channel discharge from the sewers draining local areas into the creek are evaluated considering that major inflows occur at University Avenue, Vine Street, Broadway Avenue, Race Street, Main Street, Mc Cullough Street, Springfield Avenue, and between Coler Street and Busey Avenue. The average land-use conditions of the subcatchment areas draining into the Urbana portion of Boneyard Creek are similar, thus the runoff coefficient C is approximately constant. The computed discharge ratio between the upstream and downstream reaches of the main channel, $Q_{(j-1)}/Q_j$, is given in Table 4.1.

Table 4.1 Relative Discharge Ratio at Selected Locations along Boneyard Creek.

Location	Station	$Q_{(j-1)}/Q_j$ [1]	Q_{LOCAL}/Q_{USGS}
USGS Gaging Station	9+128		1.00
D/S of Mathews Avenue Bridge	8+785	0.95	1.05
D/S of Goodwin Avenue Bridge	8+310	0.89	1.11
U/S of Lincoln Avenue Bridge	7+105	0.94	1.25
D/S of 12.5×7.5 ft Culvert	6+285	0.97	1.35
D/S of Coler Street Bridge	6+065	0.99	1.39
U/S of 200-foot reinforced concrete tunnel by Phillips Recreation Center	5+460	0.99	1.40
U/S of Main Street Bridge	4+755	0.93	1.41
D/S of Main Street Bridge	4+465	0.99	1.52
D/S of Race Street Bridge	3+600	0.98	1.52
U/S of Broadway Avenue Bridge	3+085	0.99	1.55
U/S of Vine Street Bridge	2+395	0.84	1.55
U/S of University Avenue Bridge	1+940	0.99	1.86
Confluence with Saline Branch	0+085		1.88

[1] These values are estimated only at locations where sewers with important lateral flow contributions discharge into the creek.

To properly identify the location of critical stations and bottlenecks along the studied portion of the Boneyard Creek in Urbana, the creek was further divided into two segments: **(a)** the downstream segment, located between the confluence of the Boneyard with Saline Branch (Station 0+085) and the upstream end of the Main Street Bridge (Station 4+755); and (**b**) the upstream segment which goes from the upstream end of the Main Street Bridge (Station 4+755) and the downstream end of the Lincoln Avenue Bridge (Station 6+955). The upstream segment comprises 17 reaches, whereas the upstream one is conformed by 12 reaches. In this study the overall capacity was determined for each of these segments as well as for the two reaches as a whole. The overall capacity of a channel system is here graphically represented as the locus of the possible carrying capacities of the channel (expressed in terms of the discharge exiting the system) as a function of the water stage at the system's exit station. Furthermore, a second scale representing the discharge at the U.S. Gaging station (Station 9+128) corresponding to the discharge at the exit station after accounting for lateral inflow is included at the top of the figures.

The overall capacity of the downstream segment of the Boneyard in Urbana is illustrated in Fig. 4.1. The capacity of this segment for its current conditions is limited to no more than approximately 1500 cfs, which correspons to a discharge at the USGS gaging station of approximately 800 cfs. This segment has virtually the maximum capacity (1500 cfs) for water stages at the exit lower than 701.6 ft. Three critical stations were identified within this segment, namely, downstream side of the Urbana Armory Footbridge (Station 0+885), downstream side of the University Avenue Bridge (Station 1+530), and upstream side of the Main Street Bridge (Station 4+755). Essentially, bank overflow at the first and second critical stations would occur in the event that the water stage at the confluence of the Boneyard with Saline Branch becomes higher than 701.5 ft, as indicated with circles and squares in Fig. 4.1. Overflow at the upstream end of the Main Street Bridge (third critical station) might occur in the event that the water stage at the confluence is between 693.5 and 701.5 ft. These critical conditions, indicated with triangles in Fig. 4.1, are mainly due to the obstruction offered to the flow by the Main Street and Huey's bridges which would become pressurized for such a range of stages at the exit station. The Main Street Bridge works under pressurized conditions for stages at the confluence lower than 699 ft, whereas both the Main Street and Huey's bridges become pressurized for stages at the exit between 699 and 701.5 ft. would occur at an exit stage of about 703 ft.

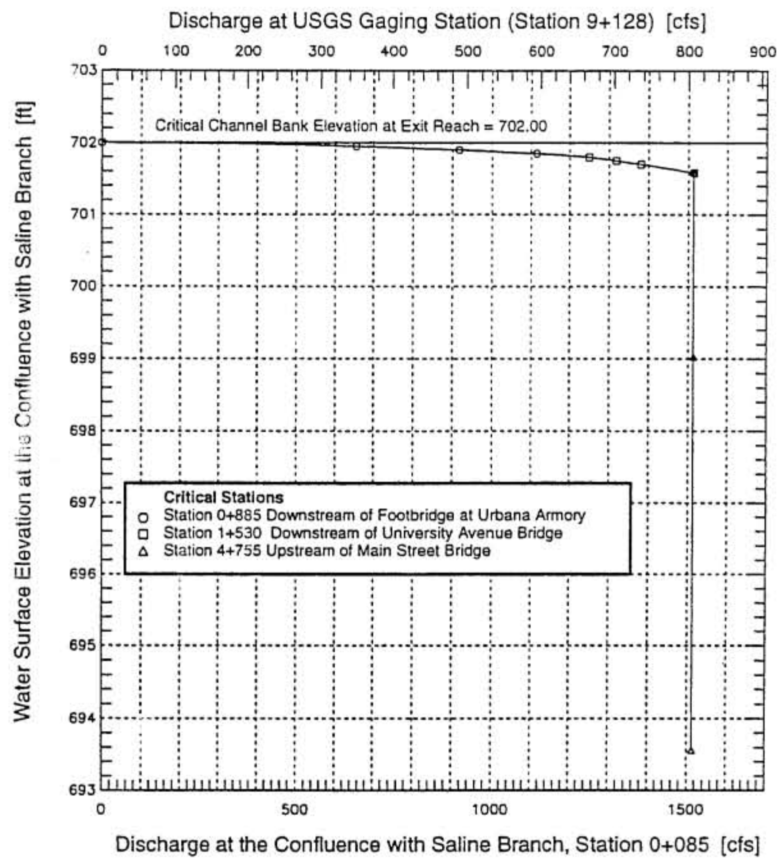

Fig. 4.1 Hydraulic Capacity of Segment of Boneyard Creek between Confluence with Saline Branch and Upstream of Main Street Bridge.

The overall capacity of the upstream segment of the Boneyard in Urbana is illustrated in Fig. 4.2. The absolute maximum capacity of the segment is approximately 1,180 cfs (820 cfs at the USGS Gaging Station) As illustrated in the figure, as the stage at the segment's exit increases the capacity of the segment decreases in a more pronounced manner than what can be observed in Fig. 4.1 for the downstream segment. Furthermore, it is noticeable in Fig. 4.2 that only for low stages at the exit of the upstream segment (Station 4+755), the carrying capacity, in terms of discharge at the USGS Gaging Station, exceeds the capacity of the downstream segment. Occurrence of critical conditions in the segment at such low exit stages, however, is rather unlikely due to the backwater effect from the downstream segment. The overall capacity of the upper segment is restricted by the limited capacity of the channel at two major critical spots, namely the downstream station of the Mc Cullough Street Bridge and all along the channel reach located between Busey and Lincoln Avenues. For water stages higher than 708 ft at the segment's exit station, the channel capacity depends upon the elevation of the bank at the station downstream of the Mc Cullough Street Bridge. The threshold capacity conditions corresponding to this range of water stages at the exit would occur for discharges smaller than 900 cfs (about 640 cfs at the USGS gaging station), as indicated with triangles in Fig. 4.2. For water stages at the segment's exit lower than 708 ft the channel capacity is restricted by the elevation of the bank along the Busey-Lincoln reach. Practically all the bridges crossing the upstream segment of the creek obstruct the flow for at least part of the range of stages in the overall capacity curve. Notably, the closing-top segments of the creek located between Mc Cullough Street and Springfield Avenue, nearby the Phillips Recreation Center, become pressurized for virtually any stage at the exit station, thus constituting a major bottleneck.

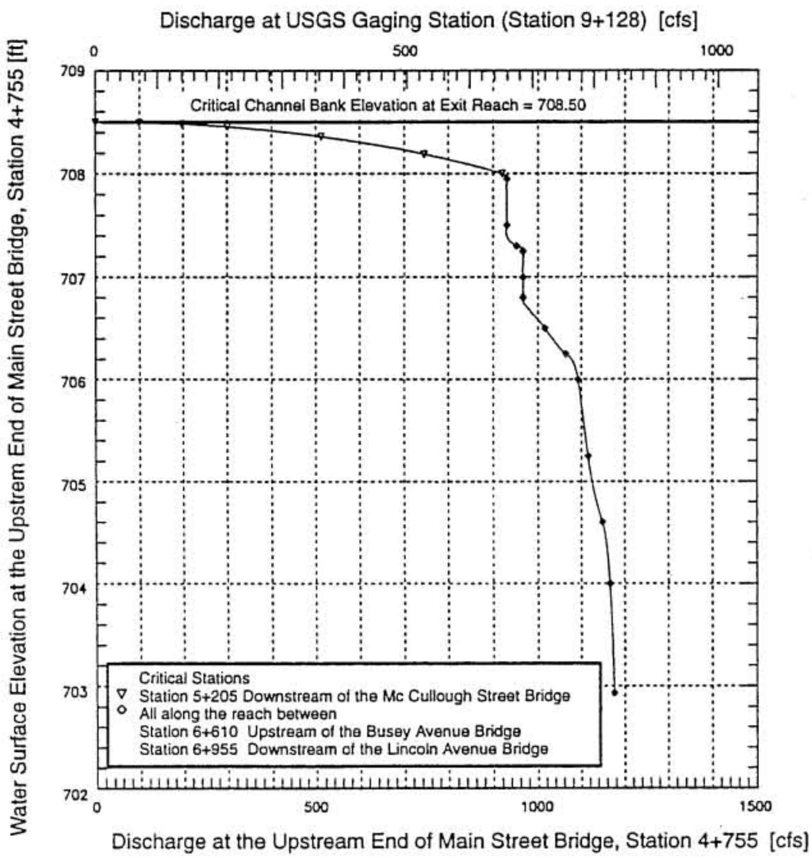

Fig. 4.2 Hydraulic Capacity of Segment of Boneyard Creek between Upstream of Main Street Bridge and Downstream of Lincoln Avenue Bridge.

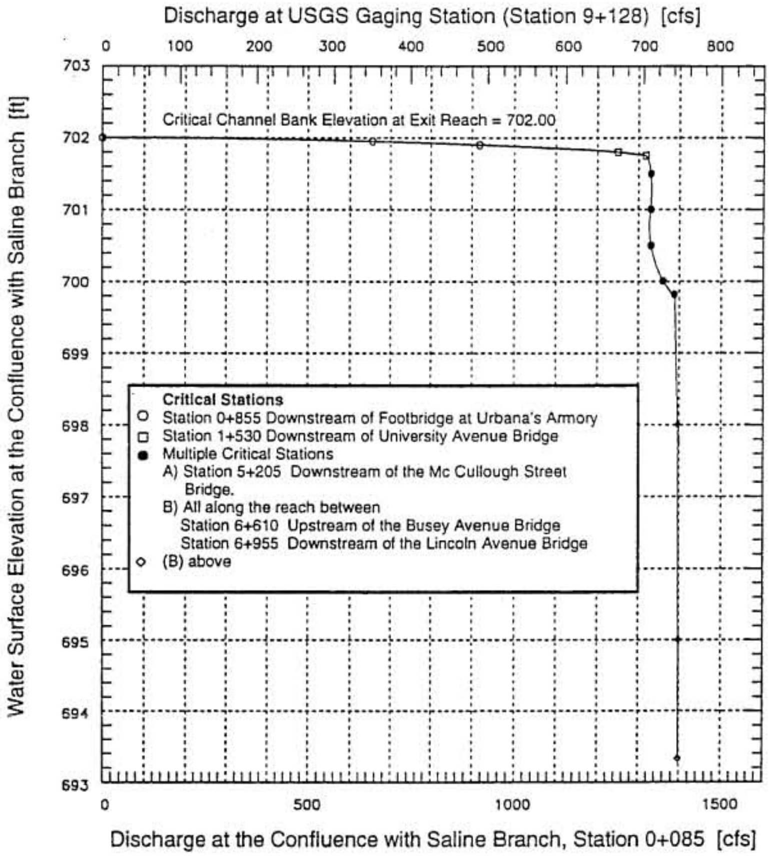

Fig. 4.3 Hydraulic Capacity of Boneyard Creek in Urbana between Confluence with Saline Branch and Downstream of Lincoln Avenue Bridge.

Studying the capacity of a channel in segments is very useful for identifying local critical points and bottlenecks, however, the study of the channel system as a whole is necessary to more precisely understand the backwater effect when the segments are working as an interacting system and to identify the most critical stations and bottlenecks that govern the system's overall capacity. The overall capacity of the Urbana portion of Boneyard Creek is illustrated in Fig 4.3. Its absolute maximum capacity is 1400 cfs, corresponding to about 740 cfs at the USGS gaging station. Four major critical stations were identified to control the capacity of the system as a whole, they are; **(a)** downstream side of the Urbana Armory Footbridge (Station 0+885); **(b)** downstream end of the University Avenue Bridge (Station 1+530); **(c)** downstream end of the Mc Cullough Street Bridge; and **(d)** all along the Busey-Lincoln reach (between Stations 6+610 and 6+955). The capacity of the creek is restricted by the elevation of the channel bank at the first and second critical stations for stages at the confluence higher than 701.75 ft, for which the channel capacity would be less than 1320 cfs (corresponding to about 705 cfs at the USGS gaging station), as indicated in Fig 4.3 with circles and squares. For the range of stages at the confluence between 699.8 and 701.75 ft the capacity of the channel will be between 1320 and 1380 cfs (705 and 750 cfs at the USGS gaging station, respectively). Such threshold conditions will be reached due to limited capacity of the channel at the third and fourth critical stations. For stages at the confluence equal to or lower than about 699.8 ft, critical conditions would be observed along the banks of the Busey-Lincoln reach. The overall capacity curves of the creek's downstream segment and of both the downstream and upstream segments as a whole, illustrated in Fig. 4.4, show that the creek's downstream segment has equal or greater overall capacity than the downstream-upstream segment as a whole. That is to say, whereas the elevation of the channel banks of the downstream segment control the overall capacity for very high water stages at the exit (higher than 701.75 ft), the downstream segment has more capacity than the whole system for stages at the confluence

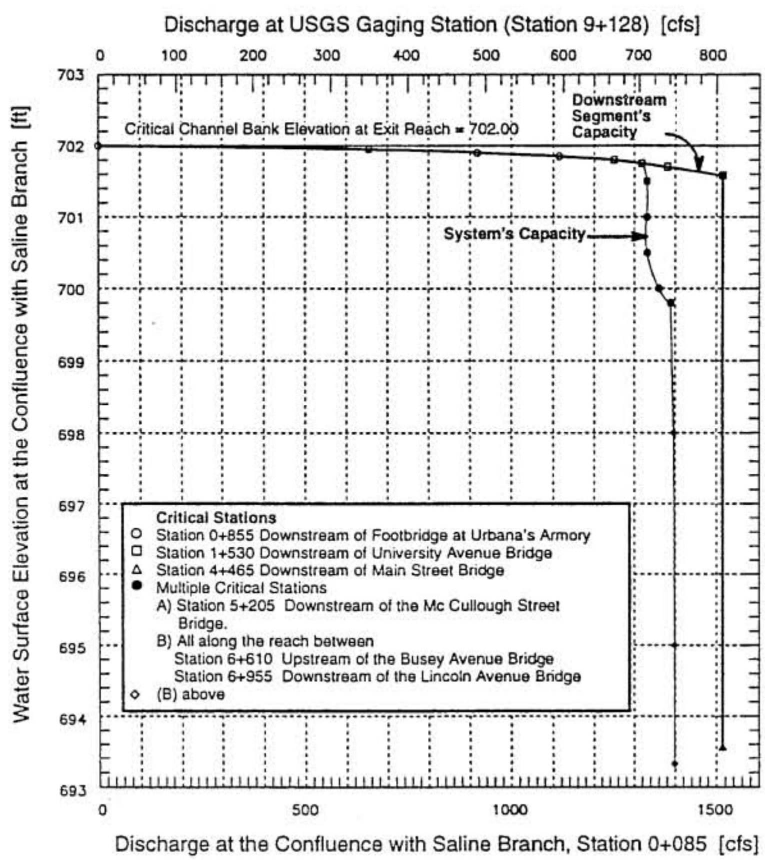

Fig. 4.4 Capacity of Downstream Segment and of Whole Portion of Boneyard Creek in Urbana.

lower than 701.75. It is then apparent that the overall capacity of the Boneyard in Urbana is due to the lack of capacity of its upstream segment. However, since the Huey's and Main Street bridges become pressurized for water stages at the confluence higher than 700 ft, thus constituting major bottlenecks, the capacity of the Boneyard in Urbana as a whole is at least partially controlled by its downstream segment.

4.2 Flood Frequency of Channel Capacity

The flow carrying capacity of a channel system can be hydraulically determined as demonstrated above. The assessment of the adequacy of the capacity of the channel system for a certain demand should be done by comparing the system's capacity with the magnitude of the storm flood to be drained. The determination of the storm flood is a hydrology problem which is beyond the scope of this report. Conventionally the storm runoff is represented by a flood frequency relationship, usually expressed as peak flood discharge values for different return periods.

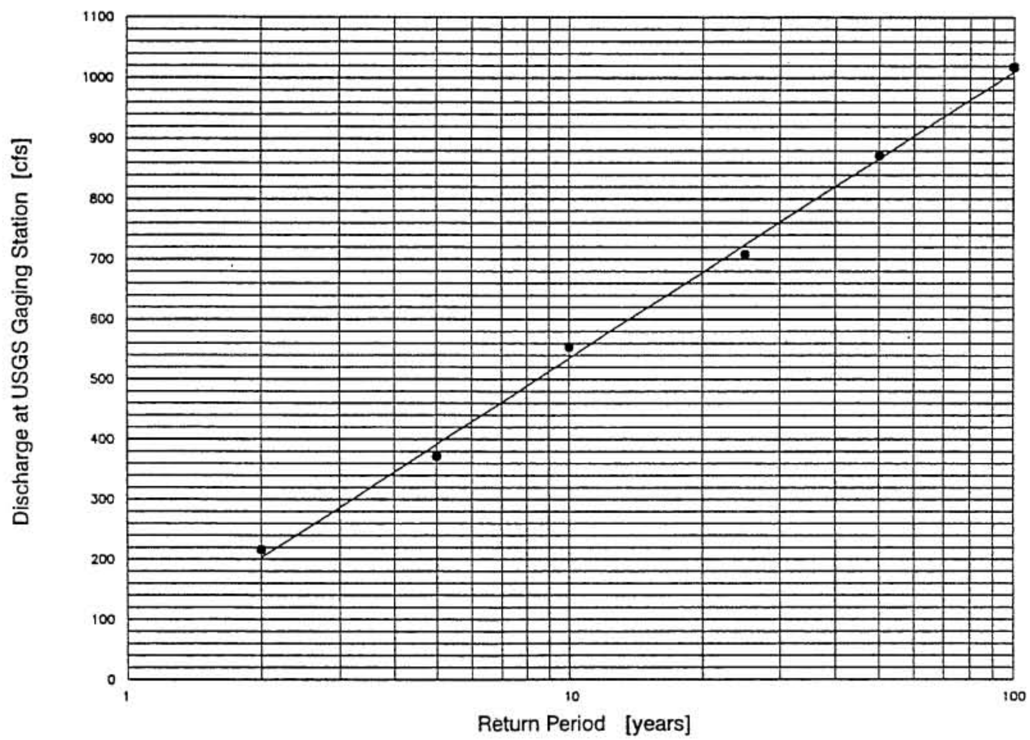

Fig. 4.5 Frequency of Peak Flood Discharge at USGS Gaging Station According to IDOT (1986).

Since no accurate flood frequency relationship for the Boneyard Creek that accounts for data adjustment due to changes in the degree of urbanization of the watershed during the period of record is available, the flood frequency based on the record at the USGS Boneyard Gaging Station at 9+128 on campus suggested by the IDOT Division of Water Resources (1986) is adopted here as an approximation. The relationship is shown in Fig. 4.5 in terms of peak flood discharge $\mathbf{Q_p}$ vs the return period in years. It should be emphasized that this curve is adopted as a demonstration while the true $\mathbf{Q_p}$ of different return periods for the May 1997 watershed condition may be higher than that shown in the figure. The frequency of the flood that the Boneyard in Urbana can carry can be estimated from Fig. 4.5 by using the Gaging Station discharge values as read on the top scale of the graph illustrating the overall capacity curve. It can be seen from Figures 4.4 and 4.5 that while the capacity of the creek's upstream segment has a return period of 40 years or less, the capacity of the whole Urbana portion of the Boneyard has a return period of about 24 years.

4.3 Impact of Major Bottlenecks on Channel Capacity

After the overall capacity of a channel system has been determined and the critical stations and major bottlenecks have been identified, it can be of special interest to evaluate the impact on the capacity of removing the major bottlenecks. The critical stations are the locations along the channel where the water is about to spill overbank or violate specified restrictions, whereas the bottlenecks are structures obstructing the flow thus causing a rise of the water stage that promotes spilling overbank at critical stations. Another very useful application of the ***HPG*** method of Yen and González is for the evaluation of the impact of the removal of major bottlenecks on the overall capacity of a channel system.

Although the main aim of this study is to evaluate the capacity of the Boneyard Creek in Urbana between its confluence with Saline Branch and Lincoln Avenue, the effect of the first two bottlenecks on the system's overall capacity has also been evaluated. As discussed in section 4.1, for stages at the confluence higher than 701.8 ft, the capacity of the creek is limited by the elevation of the channel bank very close to the system's exit. Conversely, for exit stages lower than 701.8 ft, the system's capacity is due to limited capacity of the channel at the critical stations located downstream of the Mc Cullough Bridge, and all along the Busey-Lincoln reach. Very little can be done in terms of structural changes to improve the channel capacity at the critical stations.

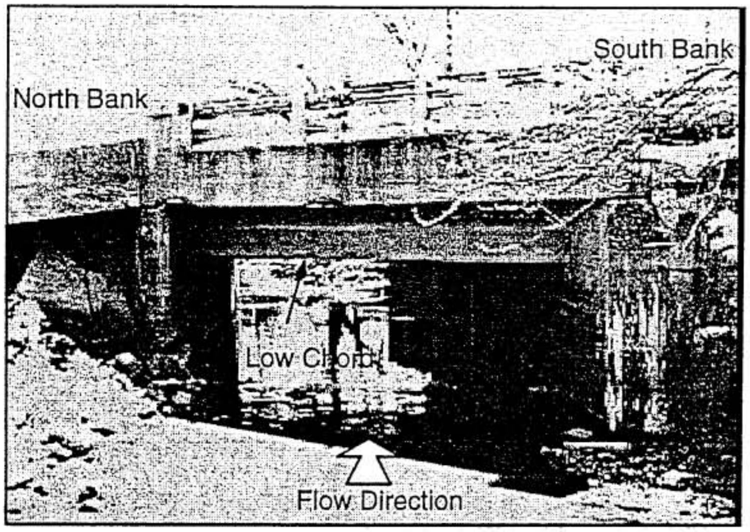

Fig. 4.6 View of Upstream Side of Huey's Bridge (Sta 2+700).

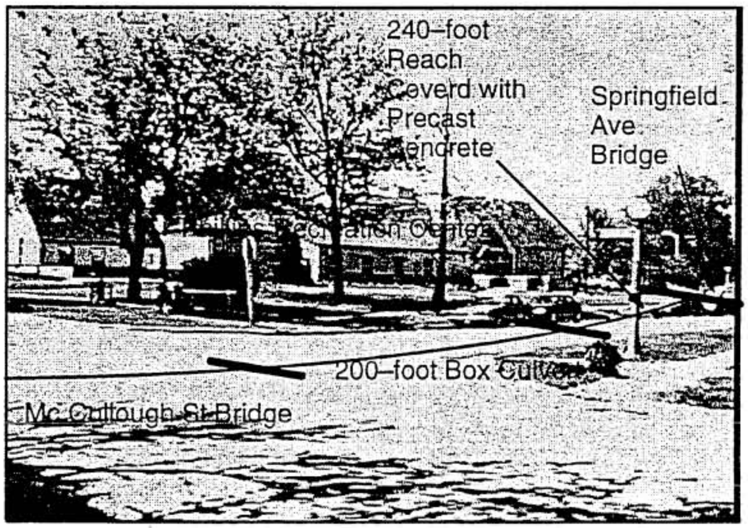

Fig. 4.7 Closing-Top Reaches by Phillips Recreation Center between Sta 5+205 and Sta 5+795.

Therefore, it seems useful to evaluate the difference in overall capacity of the system with and without some of the structures crossing the creek that might abruptly increase the water surface and induce flooding at the critical stations as if they were removed. Two such structures seem to be the major bottlenecks, the Huey's Bridge (Fig. 4.6), located between Vine Street and Broadway Avenue, and the system of four closing-top reaches by Phillips Recreation Center (Fig. 4.7). The overall capacity curves of the Boneyard Creek in Urbana for its current conditions and without the first and second bottlenecks are shown in Fig. 4.8. The curve in the middle represents the overall capacity of the channel if the Huey's Bridge were raised or removed. Similarly, the curve

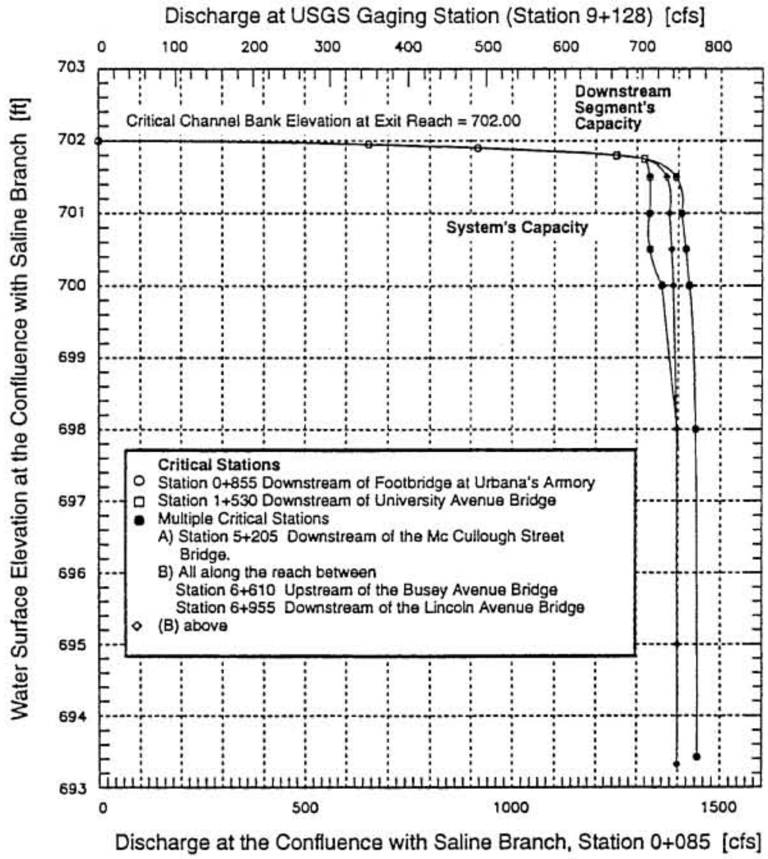

Fig. 4.8 Effect of First and Second Bottlenecks on Overall Capacity of Boneyard Creek in Urbana.

on the right represents the overall capacity if the cover of Huey's Bridge and of all the closing-top reaches located by the Phillips Recreation Center were raised or removed. As expected, these bottlenecks only affect the system's overall capacity for stages at the confluence lower than 701.8 ft. It can be noticed in the figure that the first bottleneck only affects the overall capacity of the system for a range of stages at the confluence between 698 and 701.8 ft. Raising the low chord of Huey's Bridge up to the level of the channel banks will result in an increase of the system's capacity of approximately 40 cfs for the referred range of exit stages. The overall capacity of the system if the low chord of Huey's Bridge and of all the closing-top structures by the Phillips Recreation Center were raised to the local elevation of the channel banks is illustrated by the curve on the right side in Fig. 4.8. The combined effect of the first and second bottlenecks on the system's overall capacity can be estimated by comparing the corresponding curves plotted in the figure. Raising the low chord of the second bottleneck would result in an additional increment of the system's capacity of approximately 50 cfs for exit sages of approximately 701.5 ft or lower.

Table 4.2 Flow Capacity and Approximate Flood Return Period of Boneyard Creek in Urbana as Function of Water Level at Confluence of Boneyard Creek with Saline Branch (Sta 0+085).

Channel Conditions	Water Stage at Confluence with Saline Branch (Sta 0+085)														
	701.50 ft					701.00 ft					700.50 ft				
	Q_E cfs	Q cfs	Q/Q_R	T_r yr	T_r/T_R	Q_E cfs	Q cfs	Q/Q_R	T_r yr	T_r/T_R	Q_E cfs	Q cfs	Q/Q_R	T_r yr	T_r/T_R
Conditions of May-97	1330	709	1	23	1	1330	709	1	23	1	1331	710	1	23	1
Removal of First Bottleneck[1]	1371	731	1.03	26	1.13	1378	735	1.04	26	1.13	1383	737	1.04	27	1.17
Removal of First and Second Bottlenecks[2]	1394	743	1.05	27	1.17	1408	751	1.06	28	1.22	1426	761	1.06	30	1.30

Q_E – Discharge at confluence of Boneyard Creek with Saline Branch.
Q – Discharge at USGS Gaging Station.
Q_R – Discharge at the USGS Gaging Station for channel conditions of May 1997 ; $T_R = T_{r\ \mathrm{May\ 1997}}$.
Structural Changes for Bottleneck removal options:
[1]Raising low chord of Huey's Bridge up to 706.00 ft.
[2]Raising low chord of four closing-top reaches by Phillips Recreation Center up to 710 ft

The backwater profiles along the Boneyard in Urbana for exit stages of 700.0 and 701.5 ft are illustrated in Fig. 4.9 for the channel conditions of May 1997, in Fig. 4.10 for the channel without the first bottleneck, and in Fig. 4.11 if the first and second bottlenecks were removed. The profiles shown in Fig. 4.10 clearly illustrate that Huey's Bridge, the Main Street Bridge, and the four closing-type structures by Phillips Recreation Center are major bottlenecks. The profiles in Fig. 4.9 illustrate that without Huey's Bridge, the Main Street Bridge would not become pressurized for the threshold capacity conditions and thus the downstream end of the Mc Cullough Street Bridge would not be a critical station. Also, it is apparent that for such a scenario the four closing-type structures by the Phillips Recreation Center control the capacity of the channel. The profiles for the channel without Huey's Bridge and the four closing-type structures by Phillips Recreation Center, which are the first and second bottlenecks, are shown in Fig. 4.11. It is noticeable that even though removal of these bottlenecks improves the channel capacity, for these channel conditions the critical points are the same as for the current channel conditions.

The water stage at the confluence most likely will be between 700.5 and 701.5 ft. The effect of the first and second bottlenecks on the flow capacity of the Boneyard in Urbana in this range of water stages at the system's exit is presented in Table 4.2 It can be noticed from the table that the difference in carrying capacity of the channel with and without the first and second bottlenecks is about 100 cfs (50 cfs at the USGS Gaging Station), which represents approximately 6 % of the channel capacity for its current conditions. In terms of frequency of flooding, it can be estimated, based on the IDOT frequency analysis, that the capacity of the channel with and without the first and second bottlenecks will be exceeded with a return period of 23 and 30 yrs, respectively.

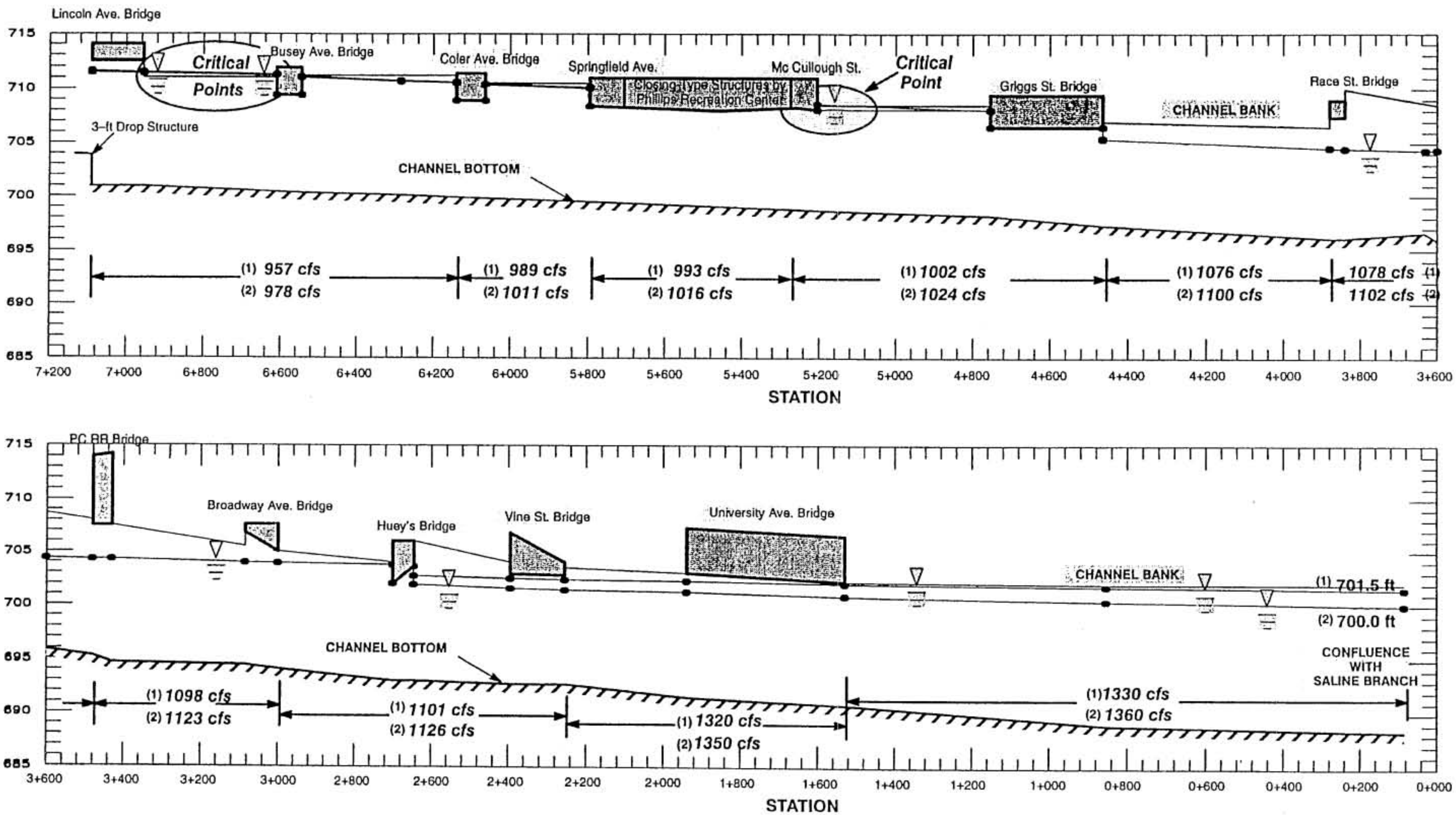

Fig. 4.9 Flow Capacities and Water Surface Profiles of Boneyard Creek in Urbana between Lincoln Avenue and Confluence with Saline Branch for Exit Stages of 700.0 and 701.5 ft, May 1997 Condition.

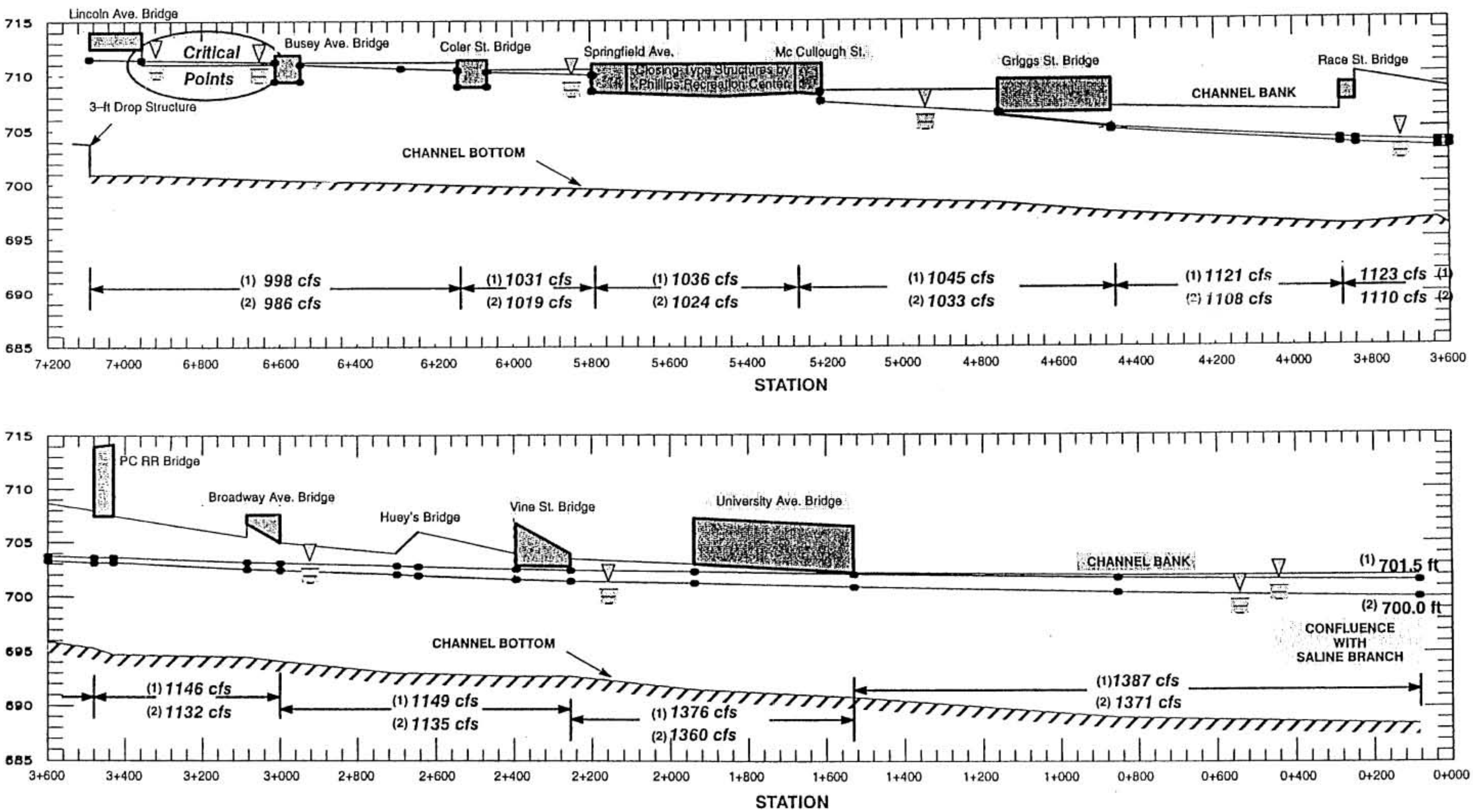

Fig. 4.10 Flow Capacities and Water Surface Profiles of Boneyard Creek in Urbana between Lincoln Avenue and Confluence with Saline Branch for Exit Stages of 700.0 and 701.5 ft, Without First Bottleneck.

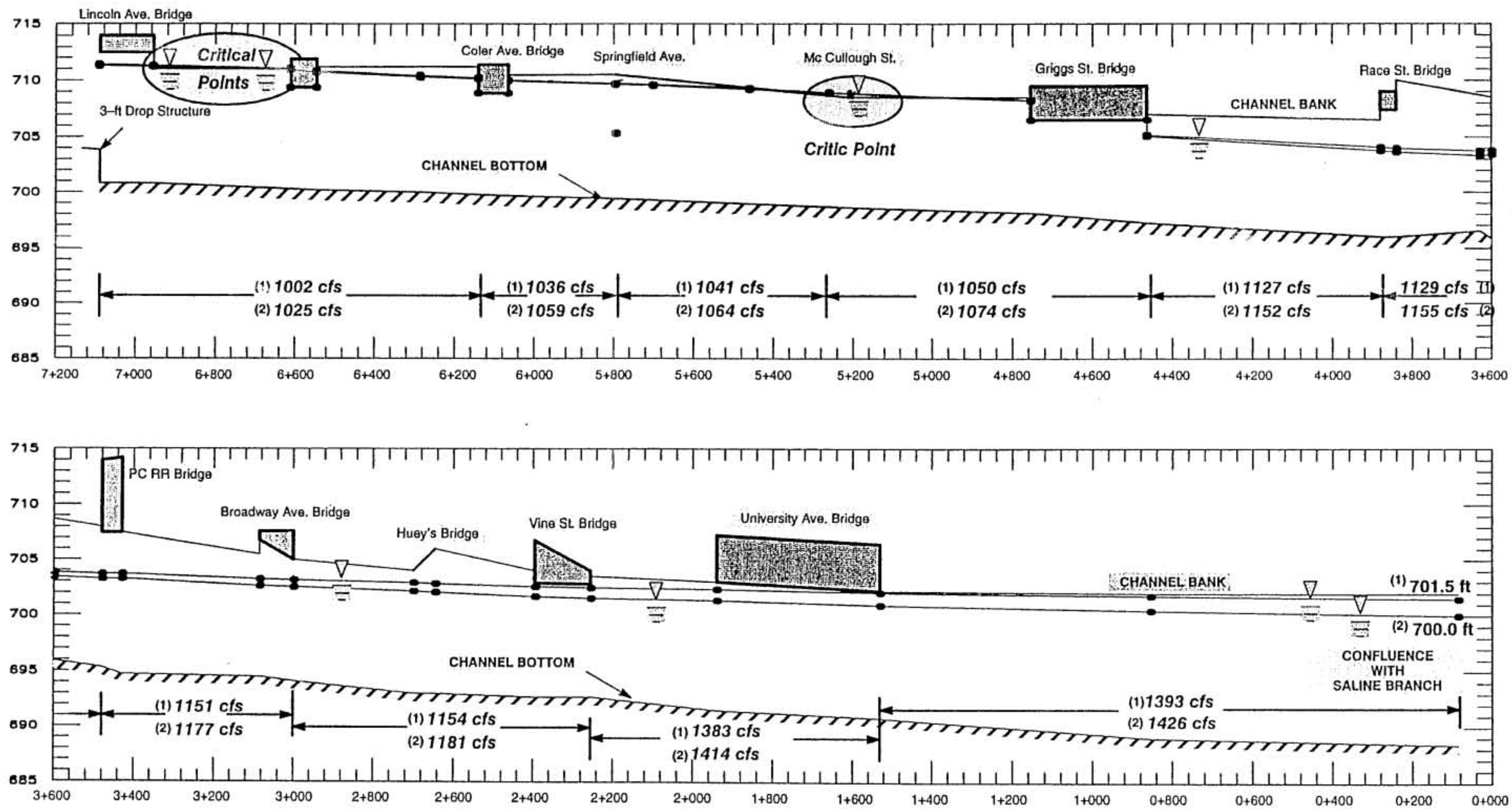

Fig. 4.11 Flow Capacities and Water Surface Profiles of Boneyard Creek in Urbana between Lincoln Avenue and Confluence with Saline Branch for Exit Stages of 700.0 and 701.5 ft, Without First and Second Bottlenecks.

5. CONCLUDING REMARKS AND RECOMMENDATIONS

The hydraulic capacity of the Urbana portion of Boneyard Creek between its confluence with Saline Branch and Lincoln Avenue has been evaluated with the ***HPG*** method of Yen and González (1994). Application of the method allowed for the estimation of the carrying capacity of the channel for its condition of May 1997, identification of major critical stations and bottlenecks obstructing the flow, and evaluation of the effect of the first and second major bottlenecks on the system's carrying capacity.

Results of this analysis show that for the most likely range of stages at the Confluence of Boneyard Creek with Saline Branch (700 to 701.5 ft), the portion of the Boneyard in Urbana between the confluence and the upstream side the Main Street Bridge has more carrying capacity than the portion upstream from this bridge up to the Lincoln Avenue Bridge. Approximately 1520 cfs for the downstream portion and from 1320 to 1400 cfs for the upstream portion, which, in terms of discharges at the USGS gaging station, are 820 cfs and from 700 to 740 cfs, respectively. This clearly demonstrates that the carrying capacity of the Boneyard in Urbana as a whole for stages at the confluence lower than 701.5 ft is due to limited capacity of the segment of the Boneyard upstream of the Main Street Bridge.

This investigation also reveals that the Huey's Bridge and the four closing-top type structures by Phillips Recreation Center are two major bottlenecks. These bottlenecks, however, do not promote flooding conditions right upstream from their location but at spots farther upstream. That is to say, for critical capacity conditions the flow through these bottlenecks switches from free-surface to pressurized, thus increasing the water stage which, due to propagation of backwater effect, results in bank overflow at farther upstream stations. The two most-flood-prone locations along the Boneyard in Urbana identified in the study are the station downstream of the Mc Culloguh Street Bridge and the channel reach between Busey and Lincoln Avenues.

The effect of the first and second bottlenecks on the overall channel capacity was evaluated in sequence by determining the capacity of the system as if the low chord of Huey's Bridge and of the closing-top type structures by Phillips Recreation Center were raised to the same elevation of the channel banks at which they would only function as open-channels. First the overall capacity of the system was evaluated as if only the low chord of Huey's Bridge was raised, and second as if the low chord of both Huey's Bridge and four closing-top type structures by Phillips Recreation Center were raised. As illustrated in Fig. 4.8, for water stages at the confluence between 701.5 and 700 ft, raising the low chord of Huey's Bridge will result in an increase of the system's capacity of approximately 40 cfs, whereas the combined effect of both the first and second bottlenecks represents approximately 100 cfs (6 %) of the ~~on the~~ system's overall capacity for its current conditions. In terms of frequency of flooding and based on the IDOT frequency analysis, the return period of exceeding the capacity of the channel for its current conditions is 23 years, whereas for the channel without the first and second bottlenecks it would be approximately 30 yrs.

In view of the results of the analysis presented here, very little can be done to increase the channel capacity at the critical stations (downstream of Mc Cullough Street and all along between Busey and Lincoln Avenues) by raising the channel banks. It seems then recommendable to remove the first bottleneck (Huey's Bridge), either totally or by raising the low chord of the bridge at the local stage of the channel banks. On the other hand, total removal of the second bottleneck seems more difficult since it would imply raising the low chord of the (a) Mc Cullough Street Bridge; (b) 200-foot long concrete tunnel build in 1926; (c) 240-foot long segment of the channel with steel sheet pile sides, concrete floor and precast concrete deck ceiling constructed in 1963; and (d) the Springfield Avenue Bridge which are designated in Fig. 2.3 as 19a, 19b, 19c, and 19d, respectively, with the consequent effects on the landscape. However, partial removal, such as improvement of reaches 19b and 19c, does not seem unlikely and is worth of further investigation.

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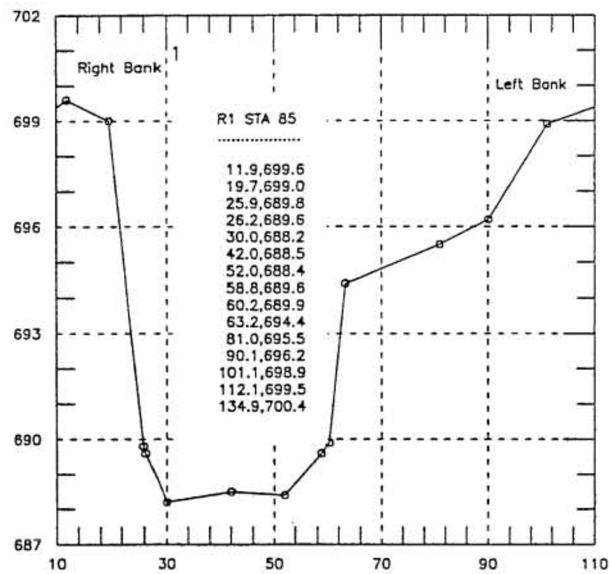
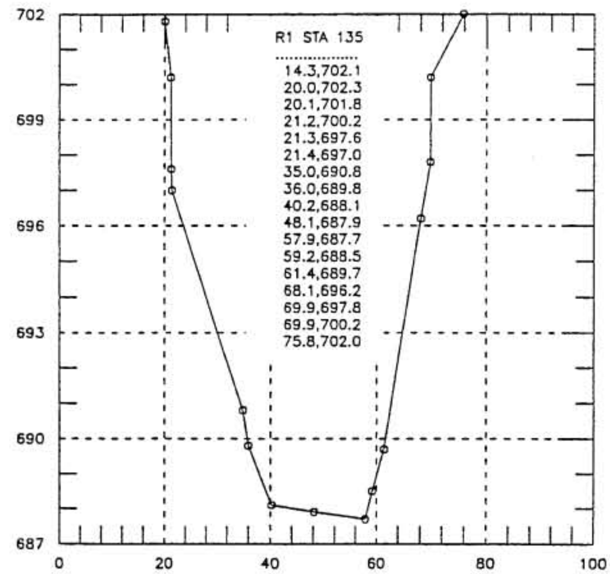
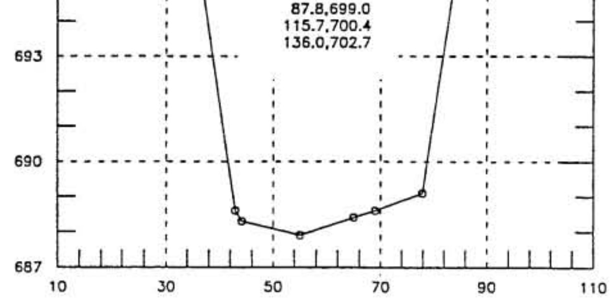
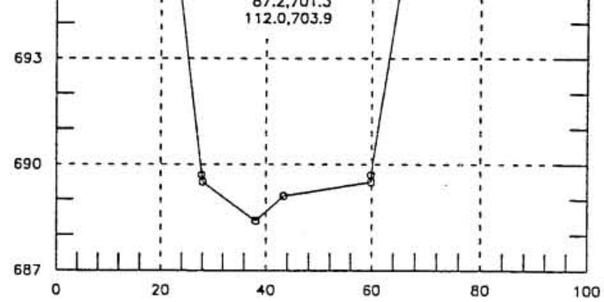
APPENDIX A
Cross Sectional Geometry of Boneyard Creek in Urbana Illinois.

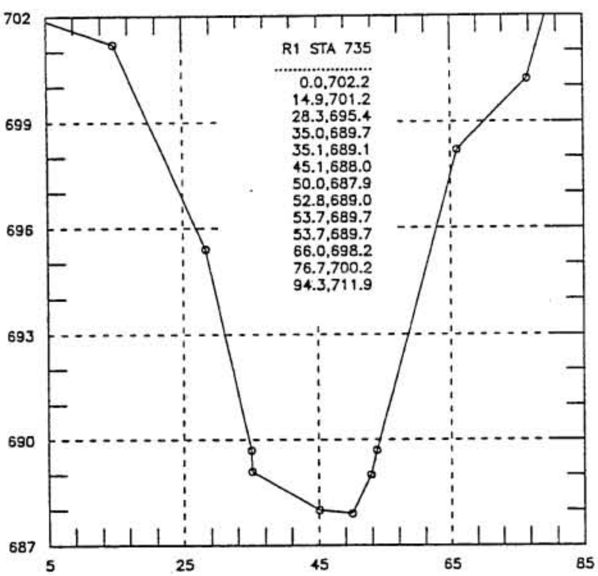




1 The channel banks in the cross sections are referred to as right and left as seen by an observer looking downstream and consistent with the labels on the cross section at the first station.



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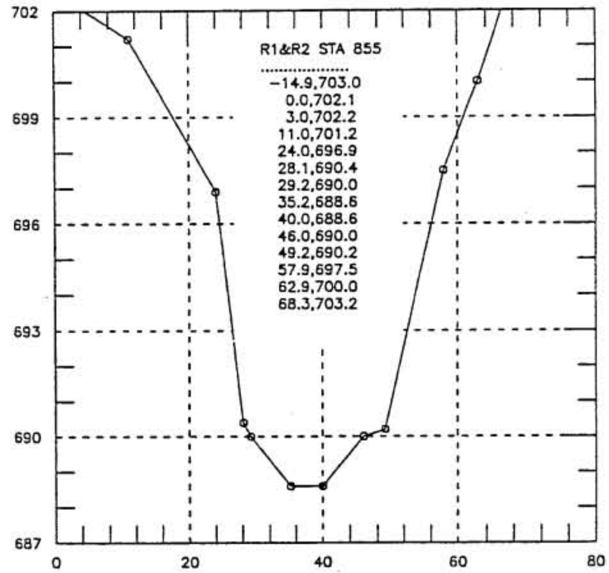
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690
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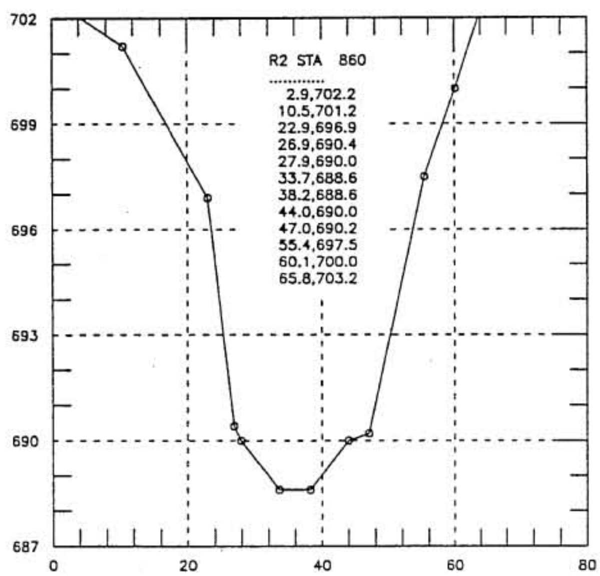
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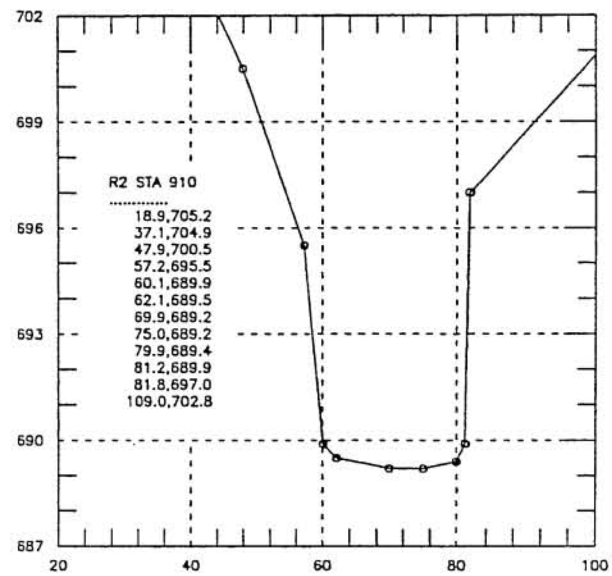
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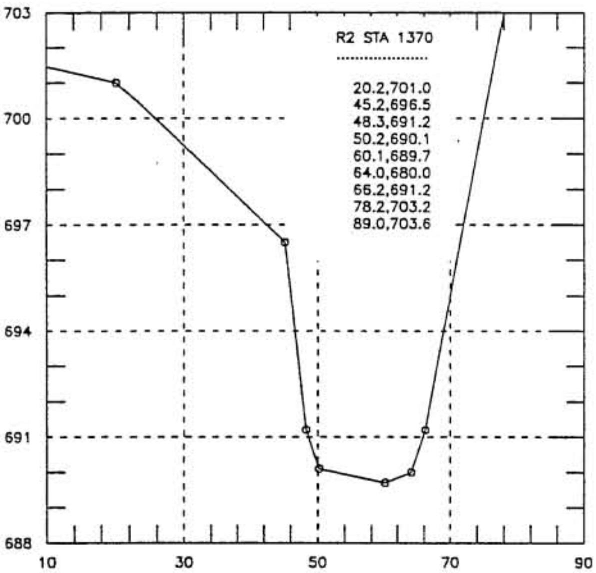
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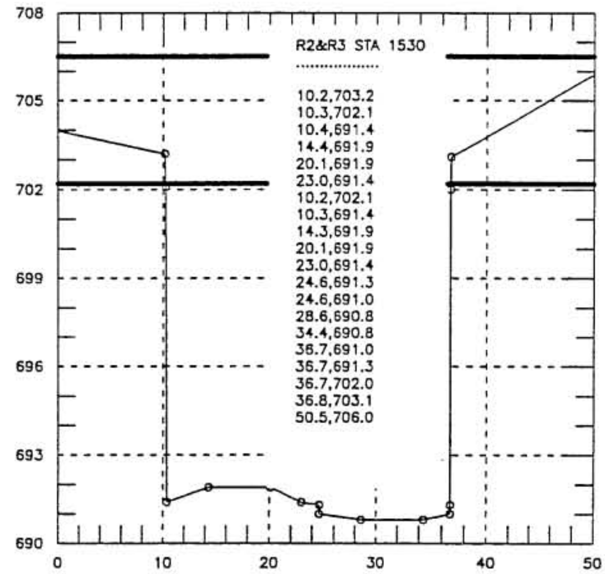
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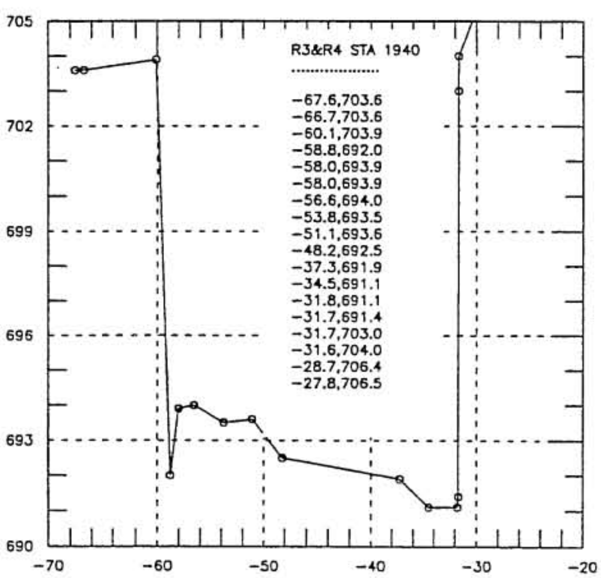
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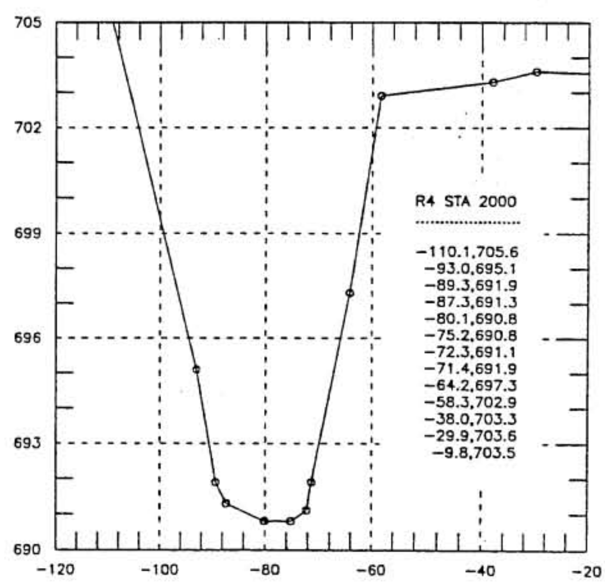
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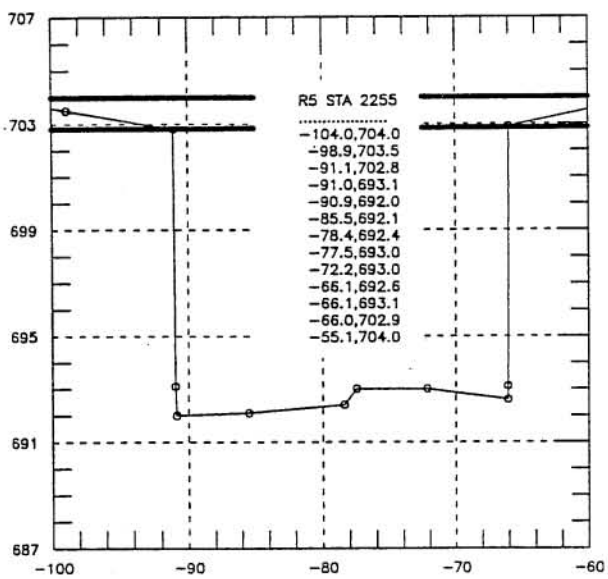
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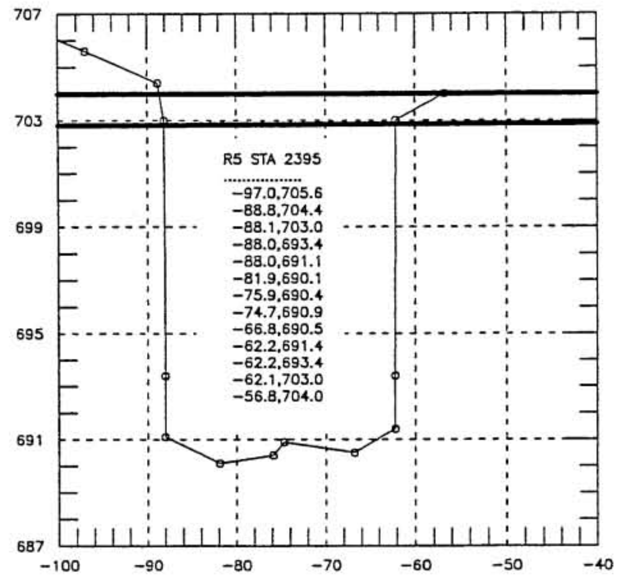
R5 STA 2395
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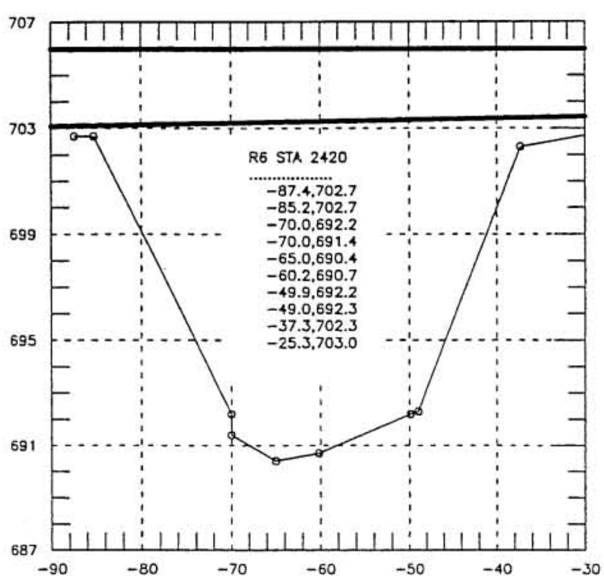
R6 STA 2420
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-70.0,692.2
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-49.0,692.3
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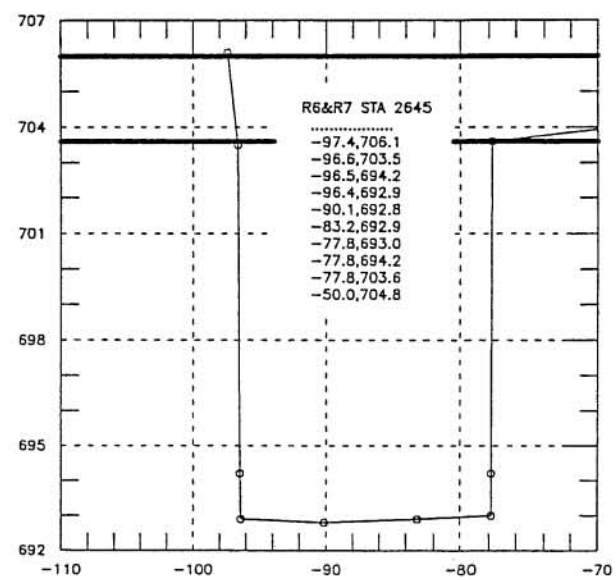
R6&R7 STA 2645
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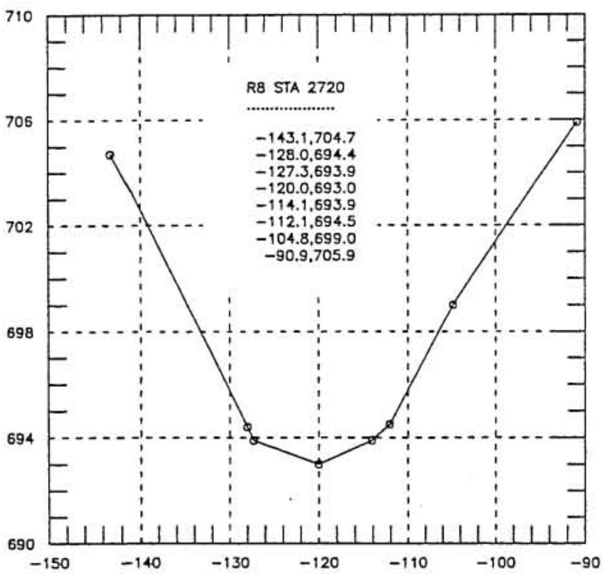
R8 STA 2720
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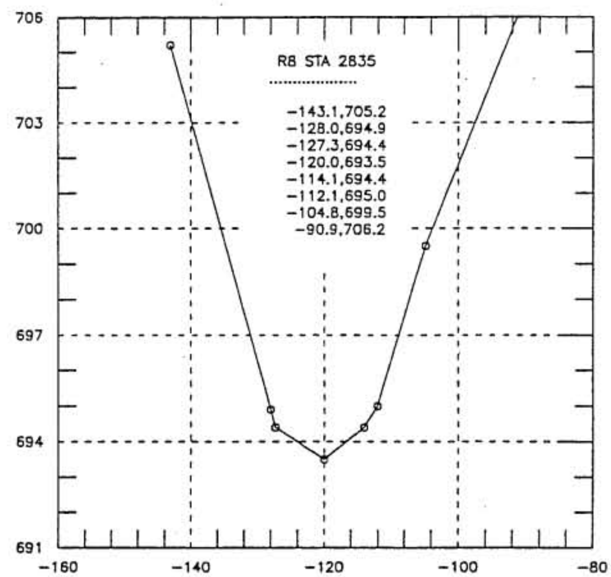
R8 STA 2835
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-112.1,695.0
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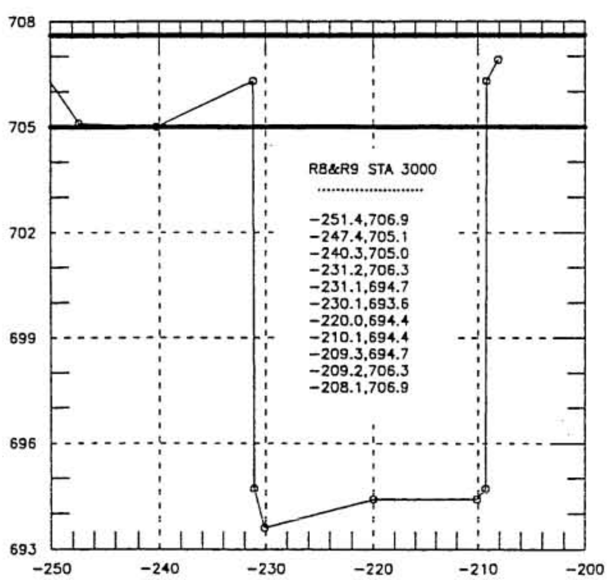
R8&R9 STA 3000
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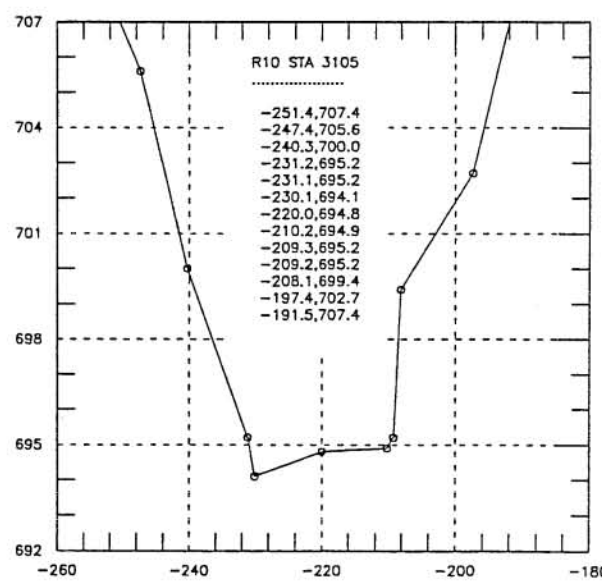
-247.4,705.1
-240.3,705.0
-231.2,706.3
-231.1,694.7
-230.1,693.6
-220.0,694.4
-210.1,694.4
-209.3,694.7
-209.2,706.3
-208.1,706.9


R10 STA 3105
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-247.4,705.6
-240.3,700.0
-231.2,695.2
-231.1,695.2
-230.1,694.1
-220.0,694.8
-210.2,694.9
-209.3,695.2
-209.2,695.2
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-197.4,702.7
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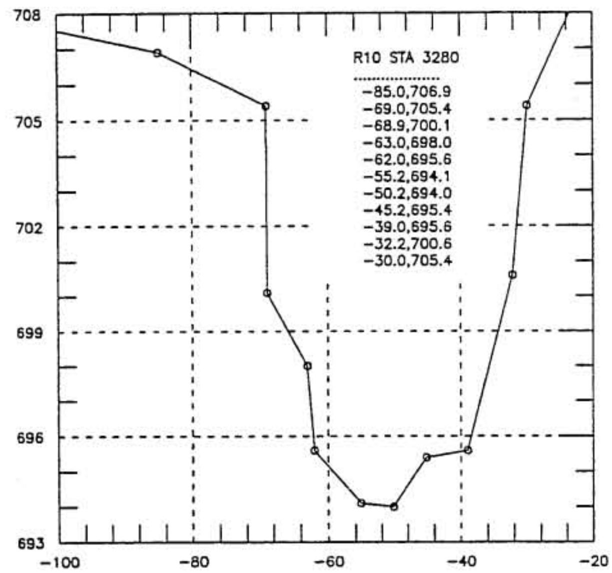
R10 STA 3280
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-69.0,705.4
-68.9,700.1
-63.0,698.0
-62.0,695.6
-55.2,694.1
-50.2,694.0
-45.2,695.4
-39.0,695.6
-32.2,700.6
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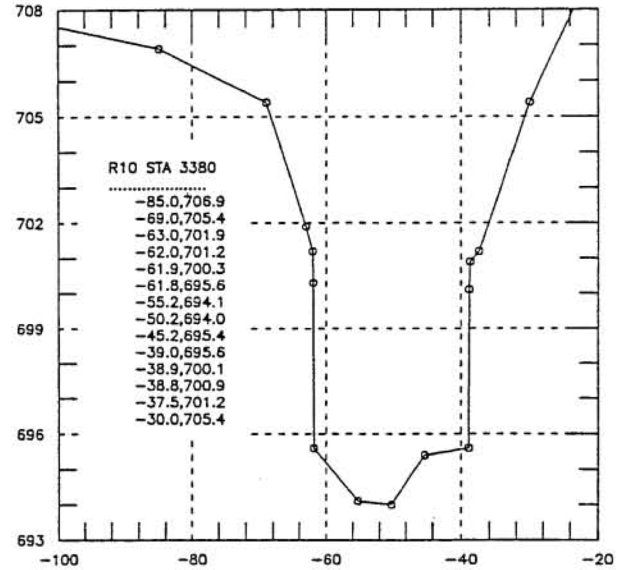
R10 STA 3380
-85.0,706.9
-69.0,705.4
-63.0,701.9
-62.0,701.2
-61.9,700.3
-61.8,695.6
-55.2,694.1
-50.2,694.0
-45.2,695.4
-39.0,695.6
-38.9,700.1
-38.8,700.9
-37.5,701.2
-30.0,705.4
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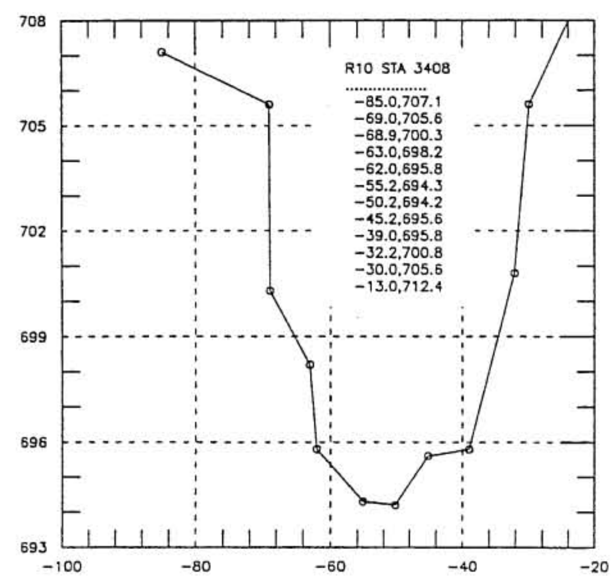
R10 STA 3408
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-69.0,705.6
-68.9,700.3
-63.0,698.2
-62.0,695.8
-55.2,694.3
-50.2,694.2
-45.2,695.6
-39.0,695.8
-32.2,700.8
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-13.0,712.4
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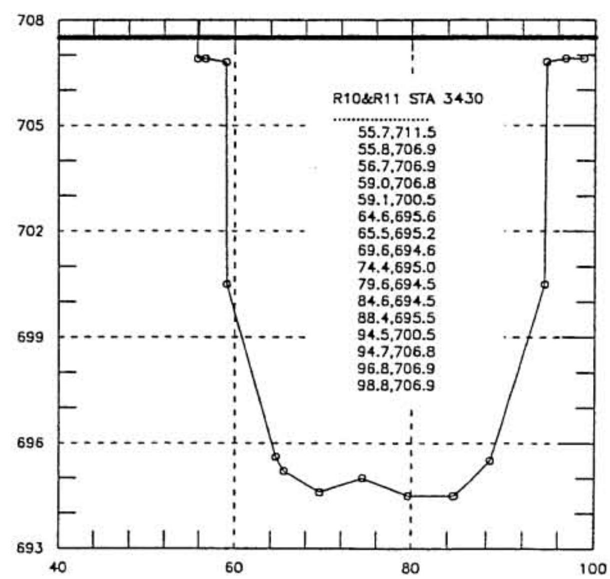
R10&R11 STA 3430
55.7,711.5
55.8,706.9
56.7,706.9
59.0,706.8
59.1,700.5
64.6,695.6
65.5,695.2
69.6,694.6
74.4,695.0
79.6,694.5
84.6,694.5
88.4,695.5
94.5,700.5
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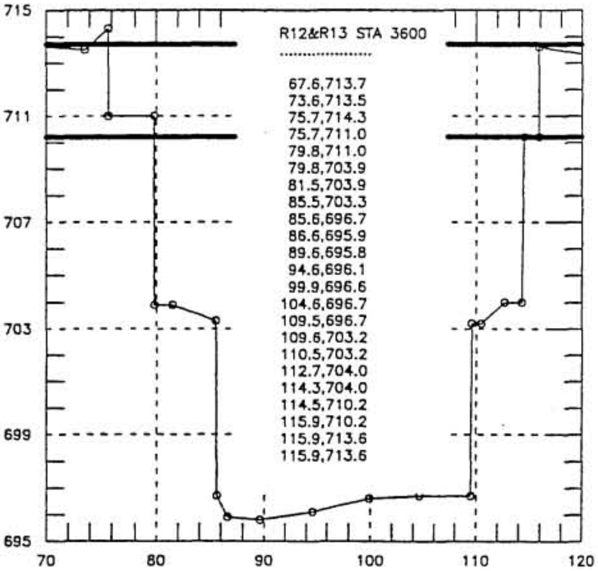
R12&R13 STA 3600
67.6,713.7
73.6,713.5
75.7,714.3
75.7,711.0
79.8,711.0
79.8,703.9
81.5,703.9
85.5,703.3
85.6,696.7
86.6,695.9
89.6,695.8
94.6,696.1
99.9,696.6
104.6,696.7
109.5,696.7
109.6,703.2
110.5,703.2
112.7,704.0
114.3,704.0
114.5,710.2
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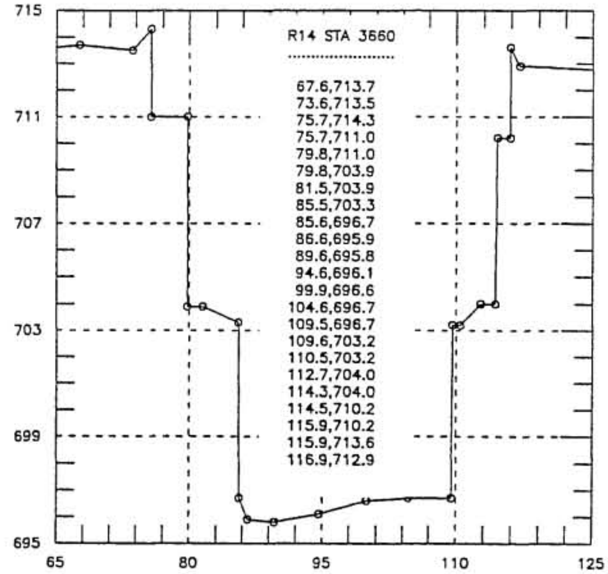
R14 STA 3660
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73.6,713.5
75.7,714.3
75.7,711.0
79.8,711.0
79.8,703.9
81.5,703.9
85.5,703.3
85.6,696.7
86.6,695.9
89.6,695.8
94.6,696.1
99.9,696.6
104.6,696.7
109.5,696.7
109.6,703.2
110.5,703.2
112.7,704.0
114.3,704.0
114.5,710.2
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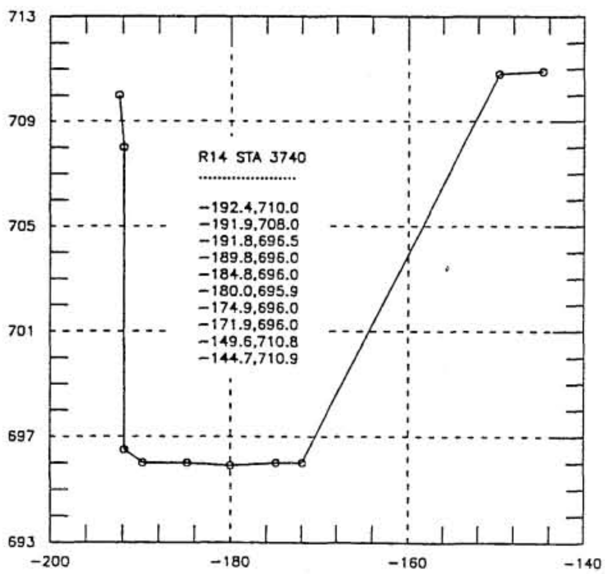
R14 STA 3740
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−191.8,696.5
−189.8,696.0
−184.8,696.0
−180.0,695.9
−174.9,696.0
−171.9,696.0
−149.6,710.8
−144.7,710.9
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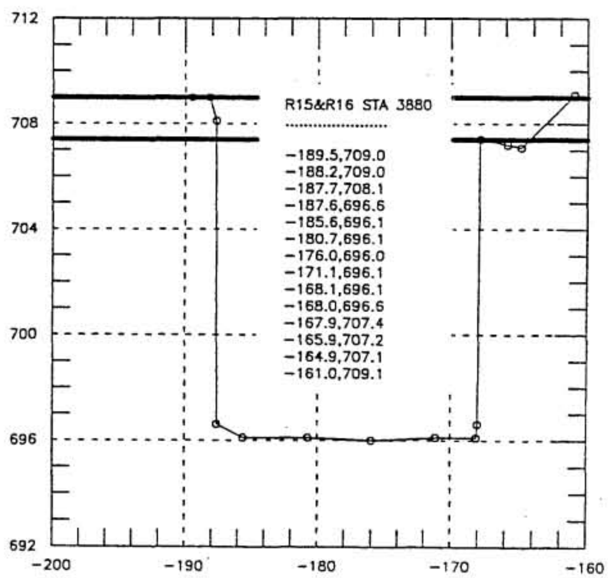
697
693
−200
−180
−160
−140


R15&R16 STA 3880
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−188.2,709.0
−187.7,708.1
−187.6,696.6
−185.6,696.1
−180.7,696.1
−176.0,696.0
−171.1,696.1
−168.1,696.1
−168.0,696.6
−167.9,707.4
−165.9,707.2
−164.9,707.1
−161.0,709.1
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704
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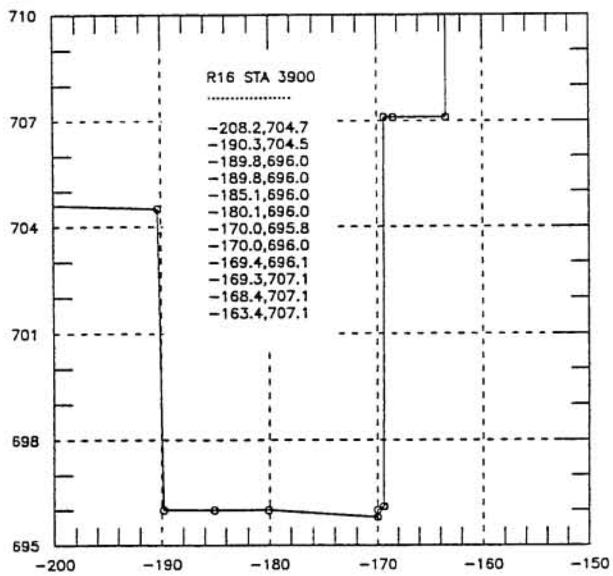
696
692
−200
−190
−180
−170
−160


R16 STA 3900
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-190.3,704.5
-189.8,696.0
-189.8,696.0
-185.1,696.0
-180.1,696.0
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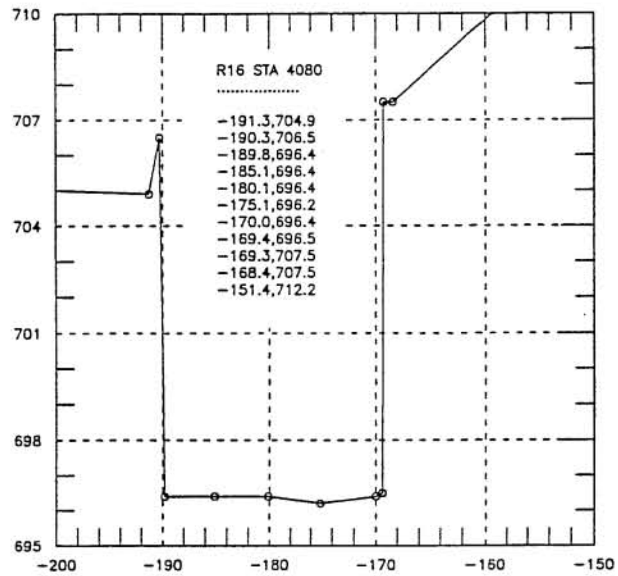
-169.3,707.1
-168.4,707.1
-163.4,707.1


R16 STA 4080
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-190.3,706.5
-189.8,696.4
-185.1,696.4
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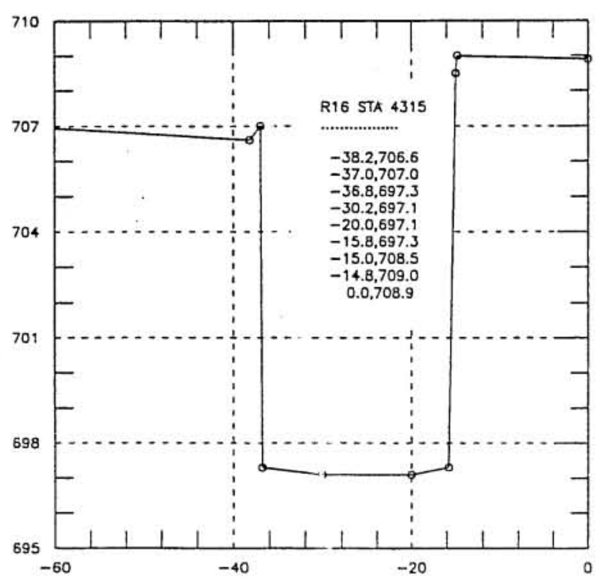
R16 STA 4315
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-37.0,707.0
-36.8,697.3
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-15.8,697.3
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-14.8,709.0
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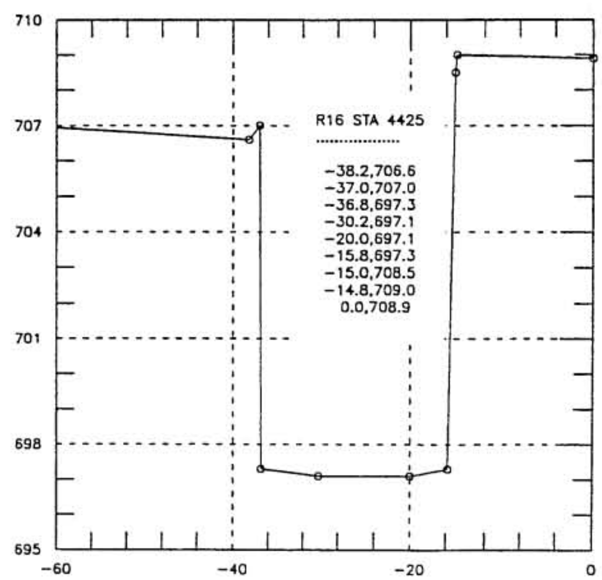
R16 STA 4425
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-36.8,697.3
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-15.8,697.3
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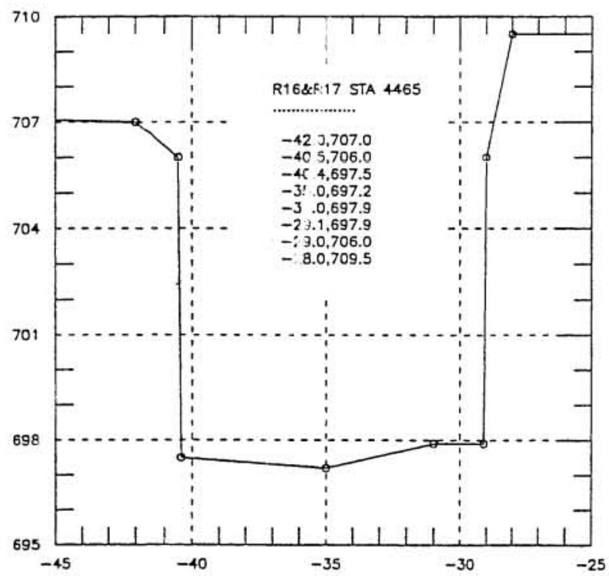
R16&R17 STA 4465
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-40 4,697.5
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-3 .0,697.9
-2 .1,697.9
- 9.0,706.0
- 8.0,709.5
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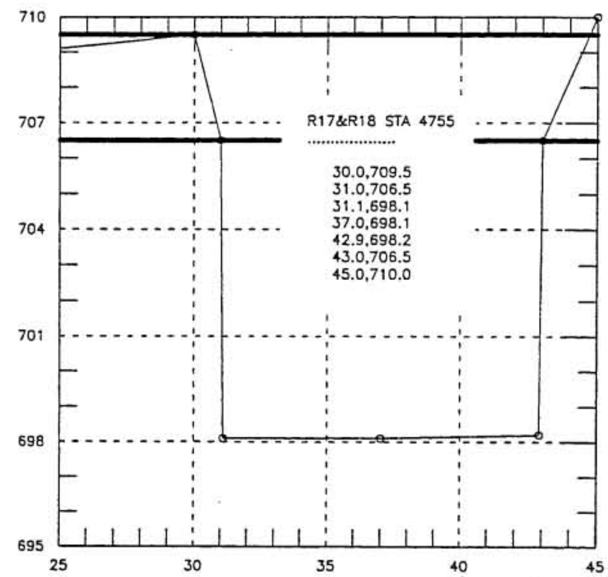
R17&R18 STA 4755
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31.0,706.5
31.1,698.1
37.0,698.1
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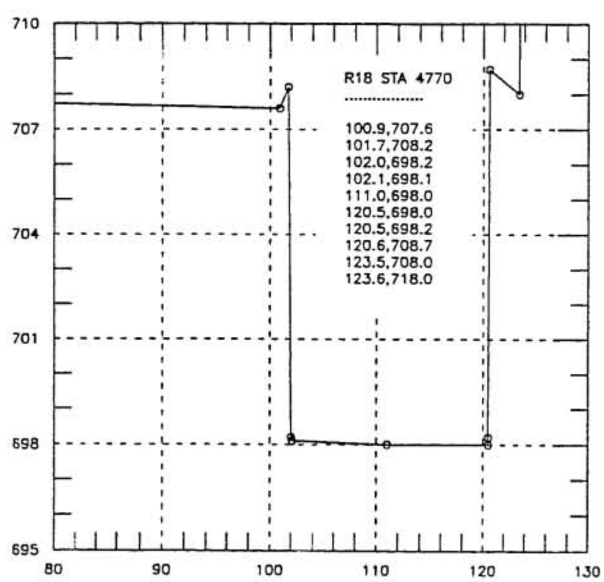
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111.0,698.0
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120.5,698.2
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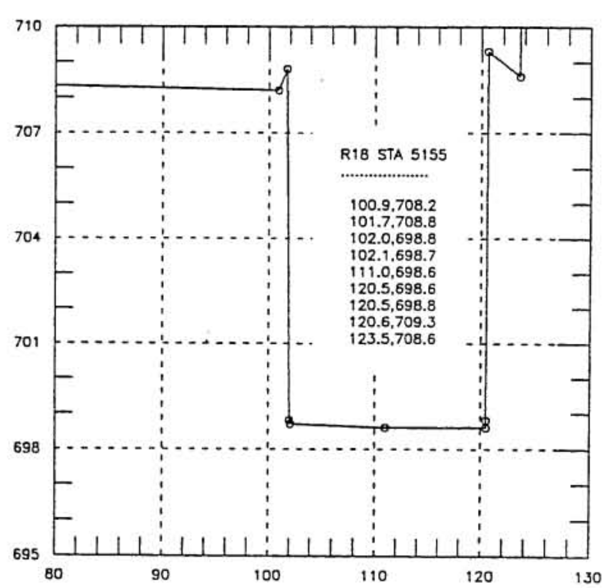
R18 STA 5155
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101.7,708.8
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102.1,698.7
111.0,698.6
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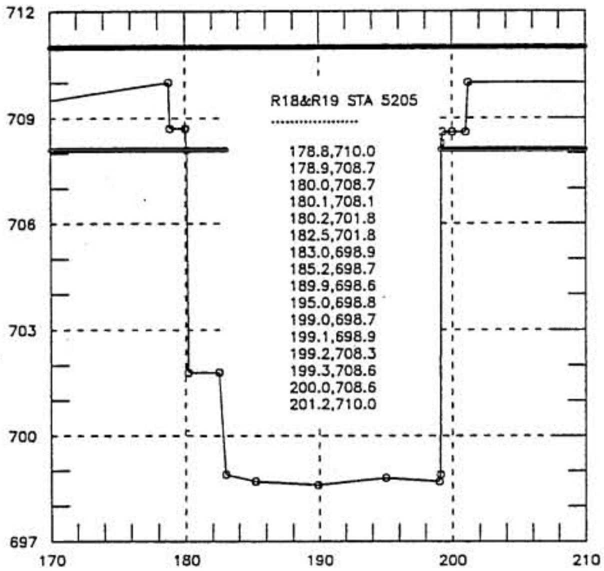
R18&R19 STA 5205
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183.0,698.9
185.2,698.7
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199.1,698.9
199.2,708.3
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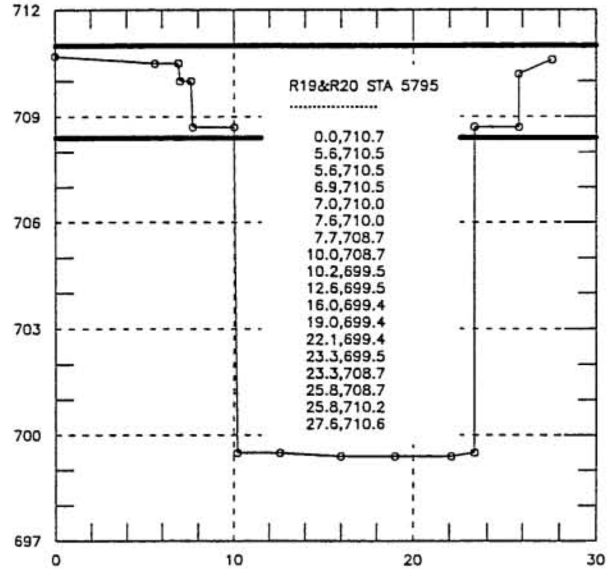
R19&R20 STA 5795
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5.6,710.5
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7.7,708.7
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23.3,699.5
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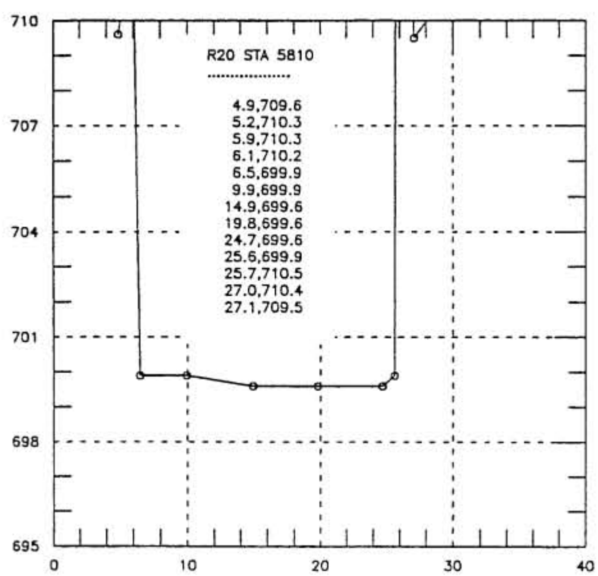
R20 STA 5810
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5.9,710.3
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14.9,699.6
19.8,699.6
24.7,699.6
25.6,699.9
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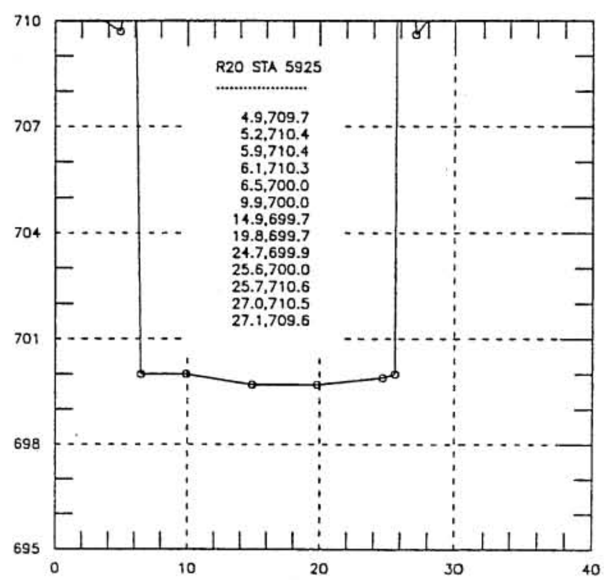
R20 STA 5925
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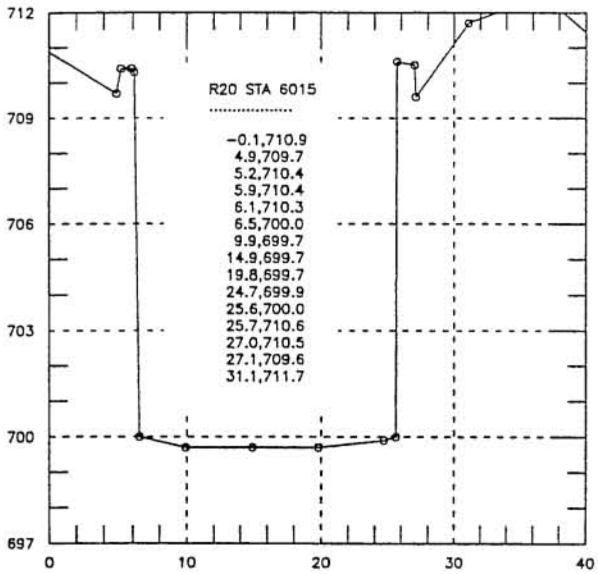
R20 STA 6015
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25.6,700.0
25.7,710.6
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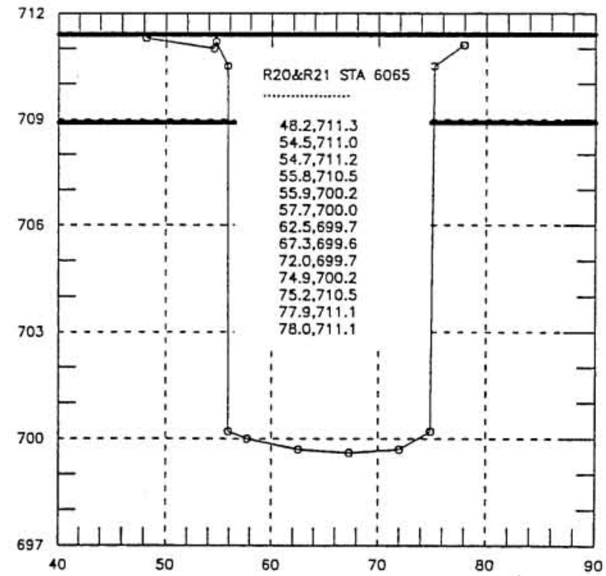
R20&R21 STA 6065
48.2,711.3
54.5,711.0
54.7,711.2
55.8,710.5
55.9,700.2
57.7,700.0
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72.0,699.7
74.9,700.2
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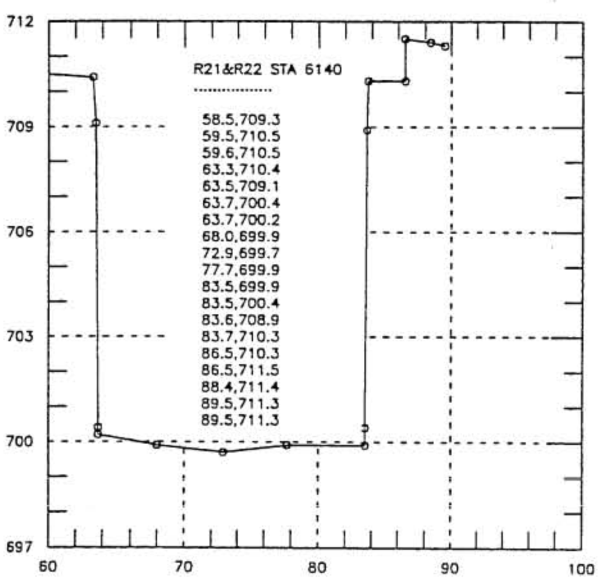
R21&R22 STA 6140
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59.6,710.5
63.3,710.4
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63.7,700.4
63.7,700.2
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72.9,699.7
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83.5,700.4
83.6,708.9
83.7,710.3
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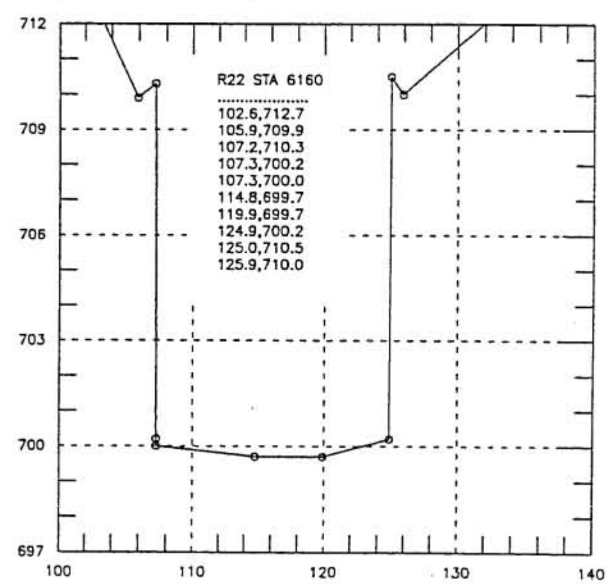
R22 STA 6160
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124.9,700.2
125.0,710.5
125.9,710.0
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703
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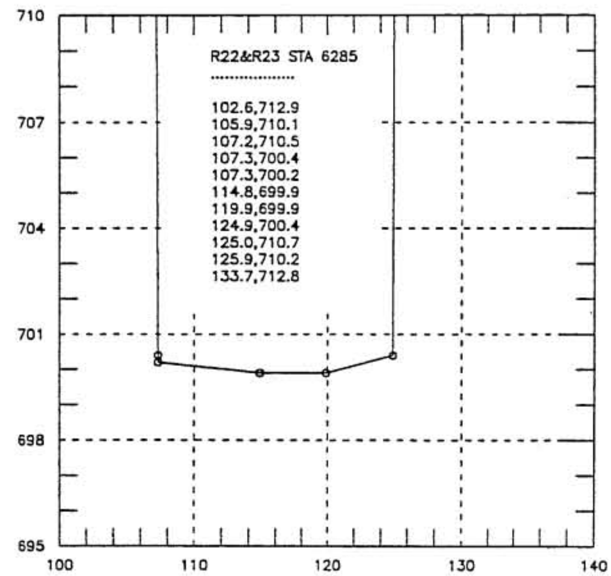
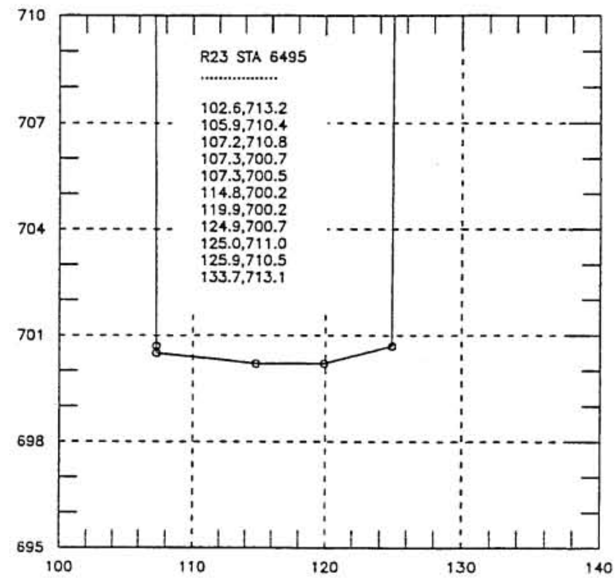
697
100
110
120
130
140


R22&R23 STA 6285
102.6,712.9
105.9,710.1
107.2,710.5
107.3,700.4
107.3,700.2
114.8,699.9
119.9,699.9
124.9,700.4
125.0,710.7
125.9,710.2
133.7,712.8
710
707
704
701
698
695
100
110
120
130
140


R23 STA 6495
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105.9,710.4
107.2,710.8
107.3,700.7
107.3,700.5
114.8,700.2
119.9,700.2
124.9,700.7
125.0,711.0
125.9,710.5
133.7,713.1
710
707
704
701
698
695
100
110
120
130
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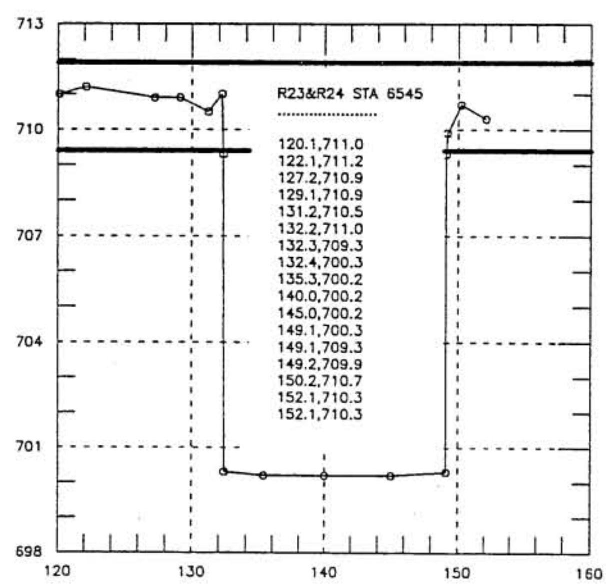
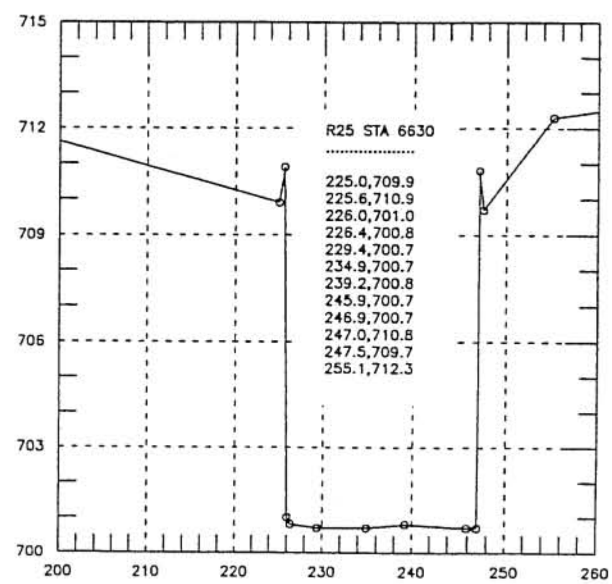
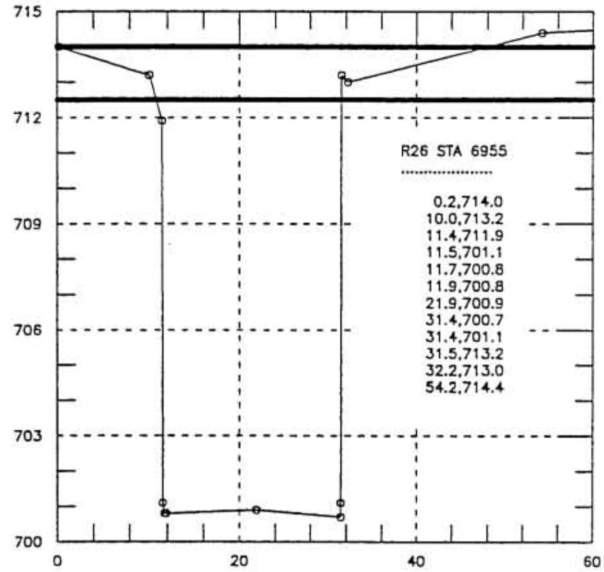
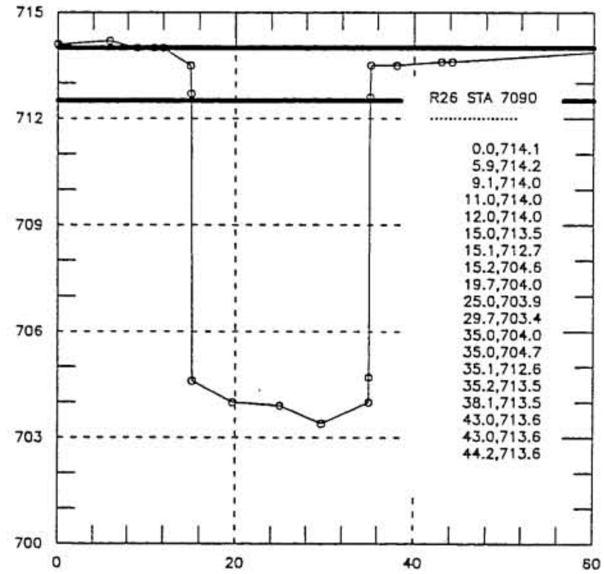

R23&R24 STA 6545
120.1,711.0
122.1,711.2
127.2,710.9
129.1,710.9
131.2,710.5
132.2,711.0
132.3,709.3
132.4,700.3
135.3,700.2
140.0,700.2
145.0,700.2
149.1,700.3
149.1,709.3
149.2,709.9
150.2,710.7
152.1,710.3
152.1,710.3
713
710
707
704
701
698
120
130
140
150
160


R25 STA 6630
225.0,709.9
225.6,710.9
226.0,701.0
226.4,700.8
229.4,700.7
234.9,700.7
239.2,700.8
245.9,700.7
246.9,700.7
247.0,710.8
247.5,709.7
255.1,712.3
715
712
709
706
703
700
200
210
220
230
240
250
260


715
712
709
706
703
700
0
20
40
60
R26 STA 6955
0.2,714.0
10.0,713.2
11.4,711.9
11.5,701.1
11.7,700.8
11.9,700.8
21.9,700.9
31.4,700.7
31.4,701.1
31.5,713.2
32.2,713.0
54.2,714.4


715
712
709
706
703
700
0
20
40
60
R26 STA 7090
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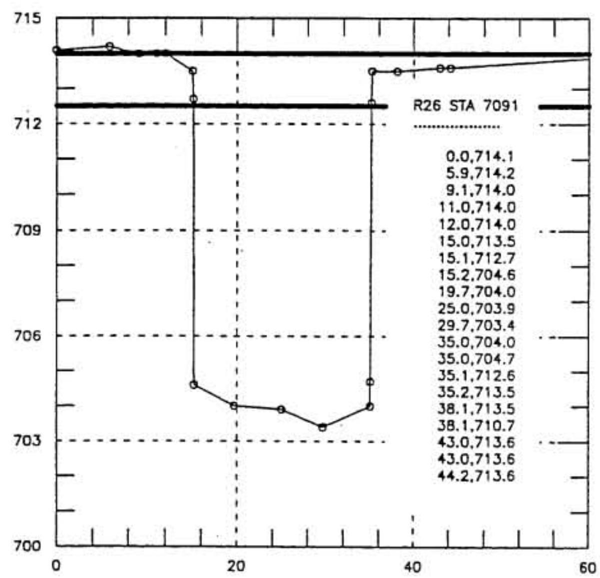
5.9,714.2
9.1,714.0
11.0,714.0
12.0,714.0
15.0,713.5
15.1,712.7
15.2,704.6
19.7,704.0
25.0,703.9
29.7,703.4
35.0,704.0
35.0,704.7
35.1,712.6
35.2,713.5
38.1,713.5
43.0,713.6
43.0,713.6
44.2,713.6


715
712
709
706
703
700
0
20
40
60
R26 STA 7091
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5.9,714.2
9.1,714.0
11.0,714.0
12.0,714.0
15.0,713.5
15.1,712.7
15.2,704.6
19.7,704.0
25.0,703.9
29.7,703.4
35.0,704.0
35.0,704.7
35.1,712.6
35.2,713.5
38.1,713.5
38.1,710.7
43.0,713.6
43.0,713.6
44.2,713.6